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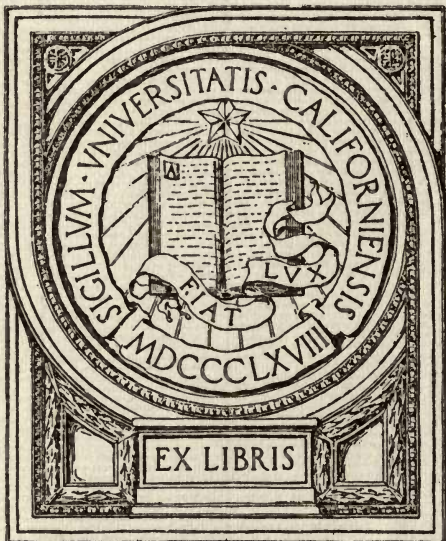
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CONTRIBUTIONS TO
GEOLOGY

GEOLOGICAL SURVEYS WITH SPECIAL REFERENCE
TO THE WORK OF THE MARYLAND
GEOLOGICAL SURVEY ¹

By WILLIAM BULLOCK CLARK

A discussion of the organization and work of a Geological Survey would not be complete without some introductory words regarding the origin of geological surveys.

Geological knowledge has been advanced by the individual working independently either in a private capacity or under university or similar auspices, or by a group of individuals brought together in an official organization, controlled generally in large measure by the lines of investigations to be followed. Coöperation is of course possible in the first case but not absolutely necessary, while team-play is an essential

¹ Part of a discussion before the Scientific Association of the Johns Hopkins University.

feature of the Survey no matter how much independence may be granted in individual instances.

Although individual effort of a sporadic sort had long existed, it was not until the appointment of Werner in 1775 as Professor at Freiberg in Saxony that geology can be said to have been recognized as an independent science and admitted as such into academic surroundings. The great influence of Werner in securing recognition for geology, although many of his conceptions were erroneous, has led to his being called the Father of Geology. For a half-century after his time much work was done by private initiative both in and out of the university to advance the science of geology, but it began to be recognized more and more that individual resources were inadequate to secure the vast number of facts in the field on which most lines of geology depend. It was then that public aid was solicited and secured, but secured not wholly because the legislator was impressed with the possibility of advancing geology for its own sake but because the geologist was able to impress him that out of this work something of a practical nature might be speedily or in the more distant future secured. It is unfortunate, perhaps, that the geologist, if he is to secure public support for such work, must be to some extent what is called a lobbyist, although the time and energy employed are not wholly lost in that his vision is broadened by frequent contact with men of affairs. Not all representatives of the people, to be sure, consider the public interest of first importance, but there are always some, often many, who do; at least that has been my experience.

It is to America that we have to look for the first recognition of the part the public may play in the support of geological work through legislative appropriations, and it was North Carolina that established the first official Geological Survey. This was in 1823, when the General Assembly of the State authorized the Board of Agriculture to pay the expenses of "geological excursions" for a period of years and appointed Professor Denison Olmsted, of the State University, subse-

quently Professor at Yale, to direct the work. South Carolina followed the example of its sister State in 1824 with Lardner Vanuxem in charge; then Massachusetts in 1830 with Edward Hitchcock as State Geologist, the first important Survey, as the Carolina organizations were rather insignificant affairs; then Tennessee in 1831 with Dr. Gerard Troost as Geologist; then Maryland in 1833 with Jules T. Ducatel, a graduate of the Sorbonne, as State Geologist, and J. T. Alexander as State Topographical Engineer. Alexander has the credit of attempting the production of the first topographical maps in the country, and although they were very crude they possess much of historical interest. In 1835 the Virginia Survey was inaugurated with W. B. Rogers as Director, the New Jersey Survey with H. D. Rogers in charge, and the Connecticut Survey with J. G. Percival and Charles U. Sheppard as Geologists. The following year, 1836, saw the inauguration of the important Survey of New York with such men as W. W. Mather, Ebenezer Emmons, Lardner Vanuxem, Thomas A. Conrad, and James Hall as Geologists, and of the Pennsylvania Survey which secured H. D. Rogers from New Jersey, and also the surveys of Georgia with John R. Cotting as State Geologist, and of Maine with Charles F. Jackson at the head. Following these come in succession the Surveys of Delaware, Ohio, and Michigan in 1837, Rhode Island in 1839, New Hampshire in 1840, Vermont in 1845, Alabama in 1847, Mississippi in 1850, Illinois in 1851, Wisconsin and Florida in 1853, Iowa in 1855, Arkansas in 1857, Texas in 1858, and California in 1860, so that prior to the Civil War only a few of the then existing States were without official Geological Surveys. The leading men of their time in American geology were in charge of this official work, organized at the public expense. Hitchcock, Emmons, the Rogers brothers, Vanuxem, Conrad, Hall, and the others I have named comprised the chief workers of their day.

The Federal Government up to this time had done little to subsidize geological research. Some explorations of the west-

ern country had been inaugurated in which geology constituted a part of the prospective plans. Among the more productive of such investigations were those made by David Dale Owen under the United States Land Office and Treasury Department in the upper Mississippi valley region in Iowa, Illinois, Wisconsin, Minnesota, and Nebraska in various years from 1839 to 1851 and by the distinguished geologists and paleontologists Newberry, Marcou, Blake, Conrad, Hall, and others in connection with the Pacific Railroad Surveys from 1853-55 under the War Department.

Only a single foreign government had inaugurated official geological work during the early portion of this period. The Ordinance Survey of Great Britain in 1830 made a small grant to H. F. De la Beche for the survey of southwest England, but it was not until later that he was definitely appointed to make a Geological Survey. Spain and Austria established Geological Surveys in 1847 and 1849, respectively, but it was not until the next decade that similar organizations were successively established in Bavaria, Portugal, the Netherlands, Norway, Sweden, and Switzerland. Some years passed before the other foreign governments followed suit.

Following our Civil War the American Government, recognizing the necessity of acquiring information regarding our great western country, established four exploratory geological organizations, two under the auspices of the War Department, the U. S. Geological Exploration of the 40th Parallel under Clarence King, and the U. S. Surveys west of the 100th Meridian under G. M. Wheeler, and two under the auspices of the Interior Department, the U. S. Geological Survey of the Territories under H. V. Hayden and the U. S. Geographical and Geological Survey of the Rocky Mountain Region under J. W. Powell. They were finally combined in 1879 with the title of U. S. Geological Survey, under Clarence King as first Director, and this organization with appropriations exceeding \$1,000,000 annually is now conducting work in every section of the country although devoting its chief energies to the West.

At the present time nearly every State in the Union is also carrying on its own official work, generally with some form of coöperation with the Federal organization.

The State Geological Survey of Maryland, as at present organized, began its operations in the spring of 1896 and is thus over twenty years old.² Like many other similar organizations the Maryland Survey is carried on in conjunction with the geological department of its leading University. In States where State universities exist they are often the headquarters of such work.

The primary object of a geological survey is to determine and describe the geological formations and depict the results on maps. In order to classify these formations intelligently one must establish criteria for their discrimination based not only on their original lithological and paleontological characteristics but also on their often highly changed texture and structure. In such a region as Maryland, which has representatives of many types of rocks, nearly every phase of geological investigation is involved. For this reason it affords a magnificent field of study for the student and has been so employed in the training of several score of graduate students at this University. The State also benefits in that it has at its command many trained or partially trained men without the expense of a permanent staff.

The differentiation of geological formations and their representation on maps has passed through many interesting phases, and a few words in this place regarding the history of geological maps may not be inappropriate. As far back as the end of the 17th century a scheme for depicting the mineral products of a country upon a map was submitted to the Royal Society of London and appears in the *Philosophical Transactions* under the quaint title of "An ingenious proposal for a

² The Ducatel-Alexander Survey came to an end in 1842 and the only official State geological work of any importance carried on in Maryland after that time until the organization of the present Survey was by Philip T. Tyson who as State Agricultural Chemist from 1858 to 1862, prepared the first geological map of the State.

new sort of Maps of Countrys, together with tables of sands and clays, such chiefly as are found in the north parts of England, drawn up about ten years since, and delivered to the Royal Society, March 12, 1683, by the Learned Martin Lister, M. D.”³ The first attempt at a geological map was apparently made by Christopher Packe in 1743 when he published with an accompanying tract “A new philosophic chorographical Chart” of East Kent, England, covering an area of about thirty-two square miles. The object of the map was chiefly to delineate the topography and agricultural soils, while the geological indications are confined to notices of the position of sea beaches, gravel pits, chalk pits, etc.

Much more complete maps of this character covering chiefly northern France on which the mineral substances were grouped in bands were communicated in connection with a memoir by Guettard in 1746 to the Academy of Sciences of Paris.⁴ Following these came maps of the same character by Füchsel⁵ in 1762, by Guettard and Lavoisier about 1770, when twenty-nine uncolored geological sheets of the map of France were issued; by Guettard and Monnet in 1780, when a folio of thirty-two sheets accompanying a mineralogical description of France was published, and by Desmarest in 1771, when an uncolored Geological Map of the Auvergne was prepared.⁶

The first colored geological map is the work of Gläser, who in 1775 depicted in colors a small district in Saxony about twenty miles long by fifteen miles broad, three tints being used: red for granite rocks with a blue dotted line to distinguish apparently one kind of crystalline rock from another, yellow for sand, and gray for limestone. Factories, limekilns, and coal, iron, copper, silver, and gold deposits were indicated by signs.

³ *Phil. Trans.*, vol. xiv, p. 739.

⁴ *Mem. Acad. Roy. France*, vol. for 1746, pp. 343-392.

⁵ “*Historia Terrae et Maris, etc.*” *Acta Acad. elect. Moguntinae* 1762, pp. 44-209.

⁶ *Mem. Acad. Roy. France*, vol. for 1771, pp. 705-775.

In 1778 Charpentier ⁷ published a book on the mineralogy of Saxony accompanied by a so-called petrographic map on which red is used for granite, purple for gneiss, pink for schists, blue for limestones, gray for gypsum, yellow for sandstone, drab for river sand, and green for clay and loam.

Palassou in 1781 ⁸ published an essay on the Mineralogy of the Pyrenees in which the routes in the south of France are colored according to the rocks they cross: green for granite, yellow for schists, and red for limestone, while sands, sandstones, and clays are indicated by signs, as are also extinct volcanoes.

Much the most important of these early colored geological maps were those of William Smith, who prepared fifteen county geological maps of England between 1794 and 1821. These and his general geological map of England published in 1815 mark the beginning of modern geological cartography. Many refinements have been introduced in subsequent years and an attempt more or less successful has been made to secure coöperation on the part of geologists the world over in the use of the same colors for rocks of the same age and character. At first all maps were colored by hand, but in recent years lithographic processes have been introduced, although the Geological Survey of Great Britain continued to color its geological maps by hand until a few years ago. The Maryland Survey has made only colored lithographic geological maps.

In addition to the strictly geological work carried on by the instructors and students of the Geological Department to which I shall again presently refer, the Survey has secured the coöperation of the staffs of several Federal and State Bureaus (1) in the making of the base topographic maps, necessary not only for the geological but other kinds of surveys; (2) in the classification and platting of the agricultural soils which are the disintegrated surface portions of the geo-

⁷ *Mineralogische Geog. d. Chursächsischen Lande*, 1778.

⁸ *Essai sur la Minéralogie des Monts Pyrénées*, Paris, 1781.

logical formations combined with vegetable debris or humus; (3) in determining the magnetic elements of variation, declination, and force so much affected by the underlying rocks, and (4) in the study of the surface and underground waters so largely dependent on the geological structure. In addition to these lines of work the Survey was directly concerned in the past in organizing the modern methods of state highway construction which were introduced in 1898, and for ten years thereafter it was the only state agency intrusted with this important service and until the transfer of its Highway Division in 1910 to the newly-organized State Roads Commission, on which it also had, by law, influential representation until 1914. During this time the Survey built 150 miles of public highways at an expenditure of nearly \$1,500,000, but more than that, developed standards of work and a trained engineering force that today largely control this important public enterprise.

The Survey has also participated in the re-surveys of many of the state boundaries, including the re-survey of the Mason and Dixon Line, and also of several county boundaries. It has made extensive geological and mineral exhibits at the Buffalo, Charleston, St. Louis, Jamestown, and San Francisco Expositions, the more important materials then secured being today maintained as a permanent exhibit in the Old Hall of Delegates in the State House at Annapolis.

Returning now to the strictly geological work of the Survey, I wish to call attention to the fact that some of our official organizations, carried away by the clamor for immediately practical results, are devoting their time much more than in the past to present commercial needs, ignoring the fact that their greatest service to the public is in studying the fundamental scientific problems furnished by the rocks even when they appear to afford no application to the industries of today. I feel that a Survey that is continually thinking of the practical results it can secure should not have the name of geological, for I dislike to feel that geology has no higher public

value than to provide means for the shrewd business man who may employ its results to acquire a few more dollars. It is my belief that if the work of a Geological Survey is properly done, with one regard to the solving of the scientific problems as they arise, it will indirectly do the commercial interests of the community a greater service in the end than if the practical aspects of the work are given first place. It would not be difficult to demonstrate this in the case of our Geological Surveys if I had the time.

Maryland possesses three provinces: first the Coastal Plain which consists of the low-lying country extending from the ocean front to a line drawn through Elkton, Havre de Grace, Baltimore, Laurel, and Washington, which consists of nearly unaltered sediments of relatively simple structure, the basal members of which date well back in geological time, in fact, before the Rocky Mountains or the Alps were formed. They afford a series of problems of great interest but quite different from those of the other areas.

Lying to the west of the landward border of the Coastal Plain and extending to the base of the Catoctin Mountain is a second area known as the Piedmont Plateau consisting of highly metamorphosed crystalline rocks cut by intrusive and extrusive eruptive rocks, the whole subjected to extensive deformation with intricate folds and faults. The rocks are very old and probably comprise the southern extension of the great Canadian shield, the oldest portion of the North American continent. Here are problems of great interest to be solved.

Beyond and extending to the western limits of the State is a third area known as the Appalachian Region that contains a great thickness of deposits lying in large part intermediate in position both as regards age and structure between those of the Coastal Plain and the Piedmont Plateau. Along their eastern margin they are metamorphosed, folded, and faulted with a large admixture of eruptive rocks that become progressively less complicated westward. In this district still other problems are presented.

I might go on and enumerate in much greater detail the innumerable questions which such an area as Maryland presents to the geologist. We have been engaged, as I stated earlier, for over twenty years in trying to reach a solution of some of these problems, but our successors will, I am sure, find enough to keep them fully occupied for another generation if it is not vouchsafed for us to keep actively employed in studying them during that time. The question may be asked, is often asked by the custodians of the public funds, will this work never end? But I must answer no, not as long as there is a science of geology worthy of the name.

THE USE OF AVERAGE ANALYSES IN DEFINING IGNEOUS ROCKS

By EDWARD B. MATHEWS

There is usually associated with the consideration of rock names and their meanings some attempt to represent the characteristic chemical composition connoted by the name. The methods employed usually consist of the presentation either of a series of analyses of individual rocks with little or no discussion of their meaning or of an arithmetical mean of a varying number of such analyses in the form of an "average" analysis also without discussion of the departures from such averages which may be shown by the analyses on which this "average" is based. Neither of these methods is very satisfactory for teaching or textbooks.

The presentation in columnar form of a series of analyses each of which includes from eight to fifteen determinations bewilders the student who seldom stops to consider just what the variations amount to either absolutely or relatively, or what relations the variants bear to the general type. This method of enumerating the actual composition of individual rocks may be eminently proper in a Handbook but fails of its purpose in a textbook.

The presentation of a single "average" analysis possesses all the charm of simplicity and ease of comprehension but fails to convey a proper conception of the complex variability underlying it. The student, with retentive memory, may hold the values assigned to the type but may gain thereby little knowledge of the real content of the term. If the rock selected is in itself sharply defined, or if the examples collected are sufficiently numerous the "average" analysis may be satisfactory. If, on the other hand, the individual rocks included under a given name are aggregates of minerals of varying composition in various proportions such as might occur in a complex of numerous related and unrelated continuous gradations without any semblance of "clustering," then the "average" analysis gives nothing more than the arithmetical mean of the quantities which have been included. As Cross¹ remarked in his criticism of the classification proposed by Loewinson-Lessing, "the grist of this mill depends entirely upon what is put into the hopper."

While even a momentary consideration shows that what has been said regarding individual concepts applies even more strongly to group concepts, the writer has considered it worth while to test quantitatively the variabilities actually involved in "average" analyses. The test is limited to anorthosites and non-feldspathic pyroxenites and peridotites and the methods employed are both graphic and arithmetic.

EXAMPLES

Anorthosite is composed of approximately a single mineral or at least of representatives of a single isomorphous series. The natural presumptions are that their analyses would represent a continuous series and their average an intermediate member. A graph of the analyses found in the literature shows no such evenly distributed series, at least so far as lime and soda are concerned, but three distinct types; one with

¹*J. Geol.*, vol. x, 1902, p. 481.

approximately 16% CaO, the most abundant with approximately 10% and a third with about $3\frac{1}{2}\%$. While the usual "average" analysis of anorthosite would represent in a general way the more abundant variety the breadth of range, the discontinuity of the series and the existence of grouping is obscured.

Dunite (Fig. 1) is another rock consisting largely of a single mineral. Here the analyses shows little variation except in the ferrous iron which shows an absolute range of 10% and a relative range of 156% of its mean amount. Magnesia shows an absolute range of 7% or about 15% of the average content. The isomorphism of the olivine group would suggest more uniform departures of the iron and magnesia from their average values.

Hornblendite (Fig. 2) is a third representative of rocks composed essentially of a single mineral or mineral group. Here the possibility of alumina in the molecule suggests wider departures from the average but the analyses show an absolute range in alumina of scarcely 9%, although nearly 80% of the average content. Ferric iron shows about the same absolute range but a much greater relative range because of its lower average content. Ferrous iron, on the other hand, with an average content similar to that of alumina, shows a relative range of 175%, while magnesia and lime show total ranges of less than 100% of the average content.

From the foregoing it seems reasonable to infer that conclusions based upon "expansions" of averages in accordance with the known isomorphism of constituent minerals are uncertain even in monomineralic rocks.

Turning to rocks consisting essentially of olivine with one or more pyroxenes or hornblende two rocks were selected.

Harzburgite or *Saxonite* (Fig. 4) composed of olivine and an orthorhombic pyroxene shows several variant types which are entirely obscured in an average analysis. The rocks which have been named harzburgite compared with those called Saxonite generally show lower alumina and lime with higher

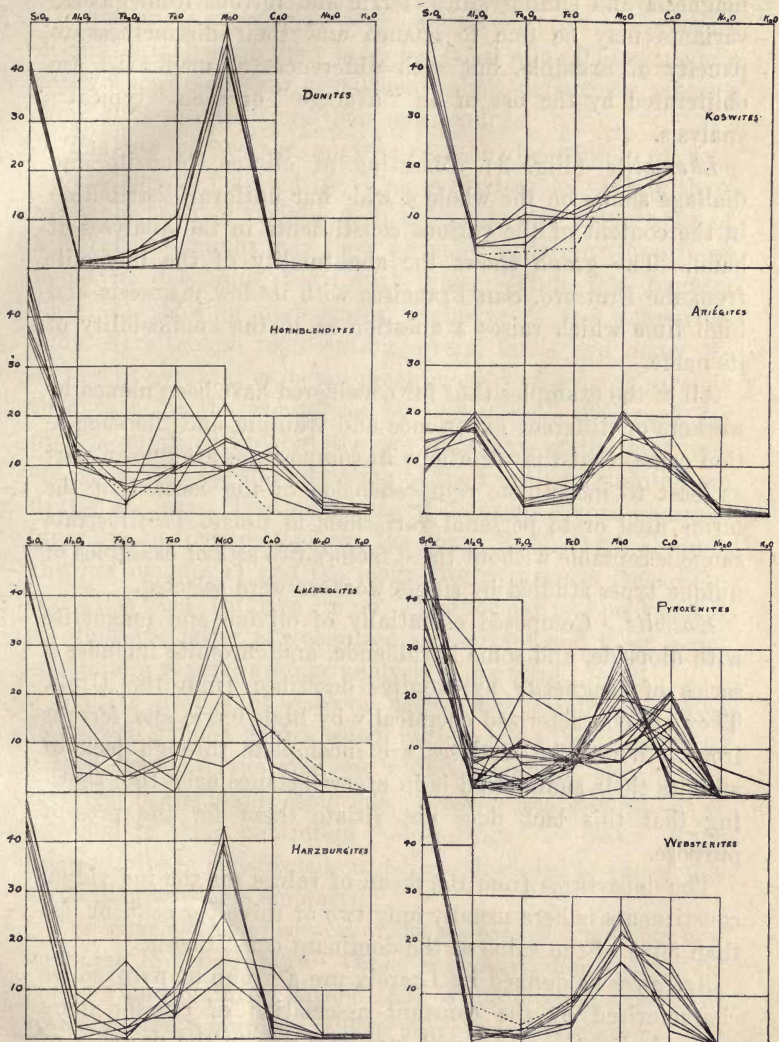


FIG. 1 TO 8.

Graphs showing composition of igneous rocks used in obtaining average analyses.

magnesia and similar silica, ferric and ferrous iron. These variants may be due to chance and their distinctness to paucity of example, but such differences as may exist are obliterated by the use of an "average" or even "typical" analysis.

Lherzolite (Fig. 3) consisting of olivine, bronzite and diallage shows on the whole a wide but uniform distribution in the content of the various constituents in the analyses at hand. The graph shows the abnormality of the lherzolite from the Protrero, San Francisco with its low magnesia and high lime which raises a question as to the applicability of its name.

All of the examples thus far considered have been named by workers of different experience and training and the suggestion comes that the variations in composition are due in part at least to incomplete comprehension of the content of the terms used or to personal variations in usage. To illustrate range acceptable without these factors two sets of examples of unique types studied by single workers were selected.

Koswite. Composed essentially of olivine and magnetite with diopside, and some hornblende, and chromite includes a series of magnetite pyroxenites described from the Urals. They are characterized chemically by high ferric and ferrous irons. While the analyses are incomplete through lack of alkalies their summation is in every instance over 100, showing that this lack does not vitiate them for the present purpose.

The departures from the mean of values for the individual constituents is here usually only two or three per cent. or less than 50% of the value of the dominant constituents.

Ariégites as defined by Lacroix are a group of pyroxenites characterized by the constant association of one or more pyroxenes and a spinel with varieties due to the presence of garnet and hornblende.

In this series the absolute range is 4% to 8% and the departures in the case of the principal constituents is not over 10% of the mean values.

From the foregoing it would appear that mature workers even in establishing their types believe it allowable to include rocks whose dominant constituents show departures ranging from 10% to 30% from their mean values.

The use of average analyses in the description of rock groups may or may not prove more serviceable. While there are more possible variations in the kinds and proportions of minerals the graphs may show no wider variations than those noted in discussing individual types. Thus the diagram (Fig. 7) showing pyroxenites, exclusive of the websterites (Fig. 8) although representing several kinds and many examples of pyroxenites, is not much more confusing or variable than that for the websterites by themselves. The peak for lime is more marked but the predominance of the magnesia and lime with the subordination of the irons and alumina are nearly as clear. The more general diagram carries aberrant types like the pyroxenite from Rosetown, N. Y. (high alumina and low magnesia) and the magnetite pyroxenite from Central City, Colo. (high in irons). The former is a poor analysis while the latter is recognized as aberrant and their inclusion in any general average analysis is doubtful.

Similar graphs of gabbro, dacite and camptonite show fairly well defined figures which indicate that the impressions gained from average analyses while incomplete may not be incorrect in the major essentials. Average analyses cannot be expected to bring out minor "clusterings" or many of the relationships in constituents which are disclosed by the simple serial diagrams here employed.

The same is true of several of the systems of projection now employed in petrography. These, moreover, often require experience and maturity beyond that of the average student of systematic petrography for their complete appreciation.

THE DELTA CHARACTER OF THE TUSCALOOSA FORMATION

BY EDWARD W. BERRY

During the enormous interval of time represented by marine sediments in other parts of the world of late Carboniferous, Permian, Triassic, Jurassic and Lower Cretaceous ages the southern Appalachian region was above sea level. Physiographically the southern half of this region is segregated at the present time into the Piedmont Plateau, the Appalachian Mountains (which die out in northwestern Georgia), the Appalachian Valley, the Cumberland Plateau, and the Interior Lowlands. Its area south of the Ohio River is over 160,000 square miles, and the actual area of this land mass during the interval from the Carboniferous to the Upper Cretaceous must have been very much greater than this, since nowhere along the margins of this massif have marine sediments of these ages been deposited near enough to its present limits to be reached by deep borings near the margin of the present Coastal plain.

The region of the southern Appalachians is one that has long interested physiographers. Hayes and Campbell, the chief contributors,¹ have recognized three base levels or peneplains which they term in the order of their ages the Cumberland, the Highland Rim and the Coosa. They consider that the original Tennessee River, which they term the Appalachian River, flowed southwestward by way of the valley of the Coosa River throughout the Upper Cretaceous and the major portion of the Tertiary until it was diverted by stream capture due to the working back across Walden Ridge of a stream in the Sequatchie valley to the west of that ridge.

¹ Hayes, C. W. and Campbell, M. R., "The Geomorphology of the Southern Appalachians," *Natl. Geographic Magazine*, vol. 6, pp. 63-126, 1894; Hayes, C. W., "The Physiography of the Chattanooga District," U. S. Geol. Survey, 19th Ann. Rept., Pt. 2, pp. 1-58. 1899.

This spectacular river capture has been disputed by Johnson² who, it seems to me, conclusively demonstrates that the present course of the Tennessee River across Walden Ridge in a winding gorge is imposed from meanders inherited from the



FIG. 1.

Map showing physiographic regions and areas of outcrop of Tuscaloosa, Eutaw, and Selma formations.

period of earliest complete baselevelling in this area, namely from the Cumberland peneplain.

The character of the Upper Cretaceous sediments of the eastern Gulf area throw considerable light on the physical

² Johnson, D. W., "The Tertiary History of the Tennessee River," *Jour. Geol.*, vol. 13, pp. 194-231, 1905.

history which has interested me chiefly in connection with the interpretation, in terms of geologic history, of the extensive fossil floras that have been found in the earliest Upper Cretaceous or Tuscaloosa formation of this region.

The Tuscaloosa formation in the area around Tuscaloosa, Alabama, and for some distance to the northwest consists of about 1,000 feet of predominantly sandy materials which give the country its present topography. These sands are usually light in color, cross-bedded and micaceous—occasionally there are traces of glauconitic layers. There are heavy beds of gravel made up of well rounded quartz and sub-angular chert pebbles in about equal proportions in places, especially toward the landward margin of the deposits and northward along the strike. In disconnected and interbedded lenses there is a considerable amount of argillaceous material—at times massive or heavy bedded, but generally laminated. Thin seams of lignite are present at various levels but these are generally only a few inches or less in thickness. The clays are often oxidized and mottled in color but they are as frequently very carbonaceous and dark in color. In some sections, as in the Big Gully section southwest of the town of Tuscaloosa, there are layers filled with prostrate logs of trees of large size. Pyrite and ferruginous oxide, forming locally indurated sandstones and gravels are generally distributed, and finely disseminated gypsum crystals are very common.

No fossils other than the remains of land plants have been found in the Tuscaloosa deposits. Usually the plant remains are much macerated and broken by water transportation and deposited in films of broken fragments in the laminated beds. Drift logs are common and these occasionally brought down cobbles imbedded in their roots (statement based on specimens collected in lignitized tree roots). There appear to have been areas of quiet waters at certain localities where the leaf remains in the clays are abundant and in a state of preservation indicating that they grew in the immediate vicinity.

The outcrop of the Tuscaloosa formation, as shown in the

accompanying sketch map, is roughly lunate in outline with the southeastern horn terminating near Montgomery, Alabama, and the other extending as an attenuated band across western Tennessee. As will be seen, the greatest width of outcrop coincides with the maximum thickness of sediments in a belt about 125 miles in length which is at right angles to the axis of the Appalachian land mass. To the northward the deposits become thinner, are prevailingly gravels and are shown by the fossil plants to be somewhat younger than the main body of the deposits.

In the interpretation of the Tuscaloosa deposits with their gravels and compound oblique cross-bedded sands, their occasional traces of glauconite and their abundance of driftwood, one cannot fail to be impressed with their delta-like character. We are now fairly familiar with the main features of delta deposits in different parts of the world³ and Grabau⁴ and Barrell⁵ have recently contributed considerable toward the interpretation of Paleozoic delta deposits. Returning for a moment to the physiographic history of the Tuscaloosa region we find that there are no sediments later than Pottsville age until the deposition of the Tuscaloosa in the earlier Upper Cretaceous. This long interval resulted in the nearly complete baselevel known as the Cumberland peneplain. There must have been some regional uplift or warping at the beginning of Tuscaloosa time to account for the sudden augmentation in river action and the inauguration of the large delta or series of deltas along the southwestern margin of the land mass. There is no evidence in the sediments that an Appalachian river flowed southwestward through the Coosa valley. This would also have brought the bulk of the sediments farther eastward than where they now occur. While I regard Johnson's evidence (*op. cit.*) as conclusive for the course of

³ Credner, H., "Die Delten," *Petermann Geog. Mitth.*, Ergänzungsheft 56, pp. 1-74, pl. 3, 1878.

⁴ Grabau, A. W., Early Paleozoic Delta Deposits of North America," *Bull. Geol. Soc. Am.*, vol. 24, pp. 399-528, 113.

⁵ Barrell, J., *idem.*, vol. 23, pp. 377-446, 1912.

the Tennessee River across Walden Ridge, I cannot help believing that the Cretaceous ancestor of this stream at the beginning of Tuscaloosa time, instead of making the sharp turn to the northwest at Guntersville, Alabama, which it does at present, continued southwestward down either Brown or Big Spring valleys and reached the sea through either the Mulberry or Locust fork of the Warrior River. This, however, is not an essential part of my argument for the delta character of the Tuscaloosa formation, since there was obviously at that time a stream or a series of streams draining to the southwest and engaged in removing the debris of the long weathered land mass.

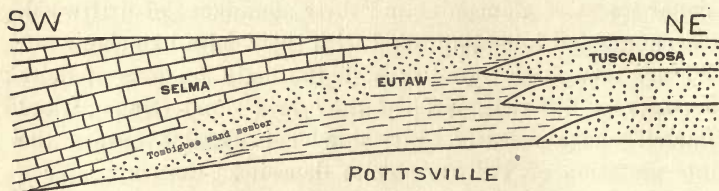


FIG. 2.

Section showing relation of the Tuscaloosa deposits to those of the Eutaw and Selma formations.

I do not wish to be understood as ignoring the fact that some of the Tuscaloosa deposits are sub-aërial and that originally the delta deposits probably continued inland up the valley or valleys for considerable distances as continental deposits of channels, flood plains and lakes. The antecedent meanders of the present streams give clear evidence of conditions that prevailed on the Cumberland peneplain that were suitable for the formation of ox-bow lakes. There must have been quiet waters in the delta itself in certain bayous or possibly lakes like lakes Salvador, Ponchartrain and Borgne of the present Mississippi delta region. Certainly the leaf-bearing clays near Glen Allen and Shirley's Mill in Fayette County, Alabama, were formed in such quiet bodies of water with densely wooded shores.

The relations of the Tuscaloosa formation emphasizes its delta character as is shown in the accompanying textfigure.

The Tuscaloosa sands grade seaward into the glauconitic sands and thinly laminated clays of the Eutaw formation which contains a sparing representation of the marine life of the time, which must have been in part at least contemporaneous with the Tuscaloosa. A few plants in the near shore transgressing phase have been collected from near Havana in Hale County, Alabama. The upper Eutaw, or Tombigbee sand member I regard as a transgressing deposit and in conformity with this interpretation it contains a much better marine fauna than the earlier Eutaw deposits. Overlying the Eutaw formation is the Selma chalk—an argillaceous limestone or calcareous clay which reaches its maximum thickness in the same region as does the Tuscaloosa sands, namely southwest of the axis of the Appalachian land mass. In this area the Selma chalk continues upward to the Eocene contact. Its outcrop as shown on the accompanying sketch map is almost perfectly lunate, and at its horns both to the east and the north it passes over into sands. The Selma, as shown by its abundance of Ostracea and other Mollusca is a shallow water deposit. So far as my observation goes it is entirely destitute of drift wood, lignite or any considerable sandy beds in the area of its greatest thickness and the point that I wish to make is that the southwestern drainage that explains the character of the Tuscaloosa sediments must have been reduced to a minimum or become practically non-existent before the deposition of the Selma chalk. The prevailing direction of the drainage during Selma time must have been to the southeast and northwest in order to explain the Ripley sands in those regions and the absence of any except the finest terrigenous materials in the main body of the Selma chalk.

Inferentially if the Cretaceous Tennessee River was a factor in the building of the Tuscaloosa delta, local warping must have broken its continuity with the Warrior drainage and started it toward the northwest before the deposition of the Selma chalk. It is possible that this may have been accomplished without local warping by the simple clogging

of its distributaries as a result of their own loads combined with decreased run off. This set of factors combined with the westward tilting that resulted in the Ripley Cretaceous and Midway Eocene seas penetrating up the Mississippi valley as far as southern Illinois is sufficient to account for the observed change, of course assuming that there has been such a change. This may be compared to the analogy of the shifting of the present Mississippi delta to the eastward by marine currents.

The remnants of heavy gravels of Tuscaloosa age that have been traced by Wade across Tennessee and into Kentucky appear to represent the gradual migration or shifting northward of such a stream. That the western Highland Rim of Tennessee is a middle or late Tertiary planation of pre-vaillingly siliceous rocks by the Tennessee River in its lower northward course is probably true but hardly within the scope of the present brief note.

THE RÔLE OF MINERALIZERS IN ORE SEGREGATIONS IN BASIC IGNEOUS ROCKS

By JOSEPH T. SINGEWALD, JR.

Though one of the latest groups of ore deposits to be definitely recognized, the magmatic segregations were firmly established as one of the major types through the classic work of J. H. L. Vogt twenty-five years ago; and it has been generally felt by economic geologists that the mode of formation of these deposits was so clearly understood that they constituted a group concerning the genesis of which there was no further question. More thorough petrographic studies of many examples of deposits classed with the magmatic segregations and metallographic investigation of the ores, especially during the last decade, have accumulated more and more evidence to show that mineralization was not so simple and did not conform strictly to the conception of a magmatic segregation in the sense in which that term is generally

thought of. The time has arrived for a definite recognition of these discordant data and a remolding of our conceptions in harmony with them.

The term *magmatic segregation* was borrowed by the economic geologist from the petrographer and used in the petrographic sense. Its application to the explanation of the genesis of certain ore deposits seemed very plausible. It is a matter of common petrographic knowledge that no large body of igneous rock is of uniform composition and that frequently the composition of a portion of the mass departs widely from the average. Consequently there were forces at work prior to or during the consolidation of the molten magma which caused local segregations of certain of its constituents. The nature of these forces has long been a matter of discussion and speculation but unanimity of opinion has not been attained and there is no thoroughly satisfactory explanation of the process which is known as a magmatic segregation or differentiation. The usual manifestation of the phenomenon is in the local accumulation of the more basic constituents of the magma.

The basis for the application of this process as an explanation of ore genesis rests on certain other observations in the field of petrography. There is present in almost all igneous rocks a group of opaque minerals, occurring as accessory constituents and with euhedral forms, the most common representatives of which are the sulphides of iron, frequently cupriferous, and the oxides of iron, frequently chromiferous or titaniferous. On account of their commonly euhedral forms, these minerals are regarded by petrographers as the earliest constituents of the magma to crystallize. Furthermore, these minerals are concentrated together with the basic silicates in the process of rock differentiation.

There are many ore deposits world-wide in their distribution possessing certain common characteristics, among which may be mentioned: (1) the ore minerals consist of one or more of the accessory opaque minerals common to igneous rocks; (2) the enclosing rock is always an igneous rock and

usually basic in composition; (3) the gangue minerals of these deposits are the same as the constituent minerals of the enclosing rock; (4) the ore body frequently passes by gradual transition into the igneous rock by a decrease in the amount of the ore minerals and increase in the amount of the silicates. These deposits appeared to be an integral part of the igneous rock in which they are found and to represent an extreme facies of the product of rock differentiation, and consequently were established as an independent group of ore deposits to which the name *magmatic segregation* was applied. The group was subdivided by Vogt into three divisions according as the metal occurs in the native, oxidic or sulphidic form. Segregations of native metals as primary ore deposits are of little economic importance, but the placers derived from such of native platinum in the Urals are our principal source of that metal. Segregations of oxidic ores are our only source of chrome ores, include countless deposits of titaniferous iron ores, and important deposits of non-titaniferous iron ores. Segregations of sulphidic ores include the nickeliferous and suprather pyrrhotites and probably a few copper sulphide deposits.

The metallic content of the segregations of the native metals is usually rather sparsely disseminated through the rock, and on account of the few examples and their minor importance, the propriety of regarding the metal as a segregation and product of crystallization from a molten magma has been little questioned. The segregations of oxidic ores usually occur well within the igneous mass, and there are so many admirable illustrations of gradation from ore-mineral bearing rock to ore body that no particular significance has been attached to the observation in a number of instances that the ore minerals are later than the silicates, and the conception of a segregation and solidification from a molten magma has been rarely challenged. The position of the sulphidic deposits has, however, been somewhat dubious from the start. They tend to occur on the periphery of the igneous mass, the sulphides often penetrate into the wallrock,

it was early recognized that in part at least the sulphides are distinctly later than the rock-forming silicates, and the rock itself has frequently undergone considerable alteration. Many geologists have consequently insisted on regarding them as hydrothermal deposits. A most interesting feature of the controversy over the genetic position of these sulphidic ores has been that the largest and most important example, the nickel deposits of Sudbury, Ontario, which has been cited by the advocates of the magmatic origin as a typical illustration of that type, is one to which most serious objection has been raised by those contending for a hydrothermal origin.

In view of the departures manifested by these deposits from the conceptions based on purely petrographic phenomena and concepts, it is interesting to see how the problem has been handled in four of the leading recent textbooks on ore deposits. The four selected are: R. Beck, *Die Erzlagertstätten*, 1909 (3rd edition); Beyschlag-Krusch-Vogt, *Die Lagerstätten der nutzbaren Mineralien und Gesteine*, 1910; W. Lindgren, *Mineral Deposits*, 1913; L. DeLaunay, *Gîtes Minéraux et Métallifères*, 1913.

Beck, in defining magmatic segregations, says: "In many instances there took place in the rock either before or during solidification from the molten state a concentration of the ores into irregular masses. . . . In spite of the concentration into a limited space, the ores of such deposits remain, what they as scattered particles in the rocks in question are, namely accessory constituents." Commenting on Vogt's observation that in certain of the Swedish and Norwegian titaniferous iron ore deposits the silicates formed first and then the titaniferous magnetite, he says, "these are departures from the rule otherwise prevailing for eruptive rocks that the iron ores belong to the earliest minerals to separate." In all chrome deposits for which he cites the sequence of crystallization, the chromite is the earliest constituent. Of the sulphidic deposits, on the other hand he says, "The strict proof of segregation from a molten magma cannot always be established with the same degree of sharpness. . . . For a

great many occurrences, which numerous authors consider a direct segregation from eruptive rocks, one must at least consider probable a later secondary recrystallization of the ores by aqueous processes which brought about a partial migration and an impregnation of the wallrock." These conclusions are based largely on his own work in 1902 and 1903 on the deposits of nickeliferous pyrrhotite and chalcopyrite at Sohland in Saxony, where he found ore deposition took place by replacement subsequent to the hydrothermal alteration of the rock, though he believes both followed immediately after its solidification.

With the exception of the treatment of the sulphidic ores, the position of Beyschlag, Krusch and Vogt is similar to that taken by Beck. Their ideas are of course largely those developed by Vogt. Their conception of the genesis of these ore deposits is that, "In the same manner in which larger masses of mica and feldspar can collect out of a granite magma, segregation of ores can take place, as for example of magnetite, titaniferous magnetite, chromite and pyrrhotite, in such igneous rocks which normally carry these ores as accessory constituents." They call attention to the fact that the ore minerals followed by the iron-magnesium silicates are the earliest constituents to crystallize in most eruptive rocks and they are also the constituents that migrate in magmatic differentiation. Magmatic segregation is distinguished from ore deposition in which mineralizers participate as follows: "The genetic difference consists essentially therein that the magmatic segregations result from a single differentiation process of the magma, whereas in the case of the pneumatolytic and contact metamorphic deposits the metallic content originally belonging to the magma is transferred to an aqueous or gaseous solution and later deposited from this through new processes." Though in most cases the two groups are considered as sharply differentiated, they admit that occasionally there are intermediate stages in which magmatic differentiation is accompanied by pneumatolytic or pneumatohydrogenetic processes. They definitely state that the chrome

ores crystallized out of a magma and that the formation of the titaniferous magnetites "depends on a pure magmatic separation, not accompanied by special pneumatolytic processes," and that the process differs from ordinary rock differentiation only in that it has proceeded much further. The characteristic association of more or less titanomagnetite with the sulphides is taken to indicate a genesis for the latter ores analogous to that of the titaniferous magnetites. In further substantiation of the magmatic origin of the sulphides is the statement that secondary alterations such as uralitization before ore deposition or contemporaneous with it has not in general occurred. They emphasize the fluidity of the molten sulphides and the consequent power of penetration into minute crevices and cracks and have proposed a subdivision of *injected sulphide deposits*, which represents intrusions of molten sulphides into the country rock. In such an interpretation of a number of the most important examples included under this subdivision, however, they stand almost alone.

The deposits under discussion are classed by Lindgren as "*Mineral deposits formed by concentration in molten magmas*," concerning which he says: "Certain kinds of mineral deposits form integral parts of igneous rock masses and permit the inference that they have originated, in their present form, by processes of differentiation and cooling in molten magmas." Of the oxidic ores he says chromite appears in all cases to be the earliest consolidated constituent, but that the titaniferous iron ores have as a rule crystallized after the silicates; but he says further about the latter: "Petrographic research has long ago shown that ilmenite with magnetite is one of the earlier products of consolidation in magmas and is contained in almost all diabases, basalts, and gabbros. . . . The larger masses of ilmenite are simply facies of the rock itself produced by concentration from the same magma." Lindgren's position concerning the sulphides is almost identical with that of Beyschlag, Krusch and Vogt, as is evidenced by such statements as, "Some of the magmatic sulphide

deposits are simple basic rocks abnormal in containing much pyrrhotite, chalcopyrite and pentlandite," and, "Some deposits in which the ore consists mainly of solid pyritic minerals present features which can hardly be explained otherwise than by actual injection of molten sulphides," in spite of his admission that "on the whole the sulphides are the latest products crystallized." In reply to the advocates of a hydrothermal origin for certain of these deposits, he charges them with having confused secondary changes with primary deposition.

DeLaunay's treatment of these deposits differs considerably from any of the preceding. The first five divisions of his genetic classification of ore deposits are the following:

1. Gîtes d'Inclusions.
2. Gîtes de Ségrégation.
3. Gîtes de Départ Immédiat ou de Ségrégation Périphérique Sulfurée.
4. Gîtes de Contact du Type Banat.
5. Impregnations Diffuses de Profondeur (includes amas pyriteux).

"Deposits of inclusions are those where a useful mineral occurs in an igneous rock in the same relation as the other constituent elements." This division is of theoretic rather than practical importance, and includes only native metals and oxides present as normal accessory constituents of an igneous rock without the intervention of mineralizers. The segregation deposits, he says, might be regarded as having been effected without intervention of volatile constituents, nevertheless the general opinion today is that water and probably other mineralizers have played a rôle, though he considers them formed in a medium poor in mineralizers. The ores are native metals and oxides. The *Gîtes de Départ Immédiat*, or peripheral sulphide segregations, he says, have usually been considered examples of true segregations which differ from the internal oxidic segregations by their position and nature. DeLaunay believes it necessary, however, to

separate them entirely from the true segregations, for there has been a concentration of sulphides not only in the rock but at its contact, and they appear to him to be a close parent to contact metamorphic deposits which are formed when the wallrock is a limestone. They represent a type of ore deposition in which mineralizers are more abundant and active than in the preceding. The very close relation postulated between these deposits and typical contact metamorphic deposits indicates clearly that he does not look upon them as representing a crystallization from a molten state. The mineralization of the last group is analogous to that of the fourth, the types of deposits included under it being formed where the country rock is other than a carbonate rock. It includes most of the deposits classified by Beyschlag, Krusch and Vogt as injected sulphide deposits. There are no sharp lines of demarcation between these groups, as DeLaunay recognizes a complete transition from purely igneous deposits to hydrothermal veins and that in some instances it is difficult to decide between fusion and solution.

In an attempt to settle some of the doubtful points concerning the mode of formation of the sulphidic ores usually classed as magmatic segregations, C. F. Tolman, Jr. and A. F. Rogers of Stanford University have just published the results of a very comprehensive petrographic and metallographic investigation of those ores as a monograph entitled "A Study of the Magmatic Sulfid Ores." They formulate a number of statements which they find applicable to all of the deposits studied, the most significant of which are:

1. The first minerals to form are olivine, the pyroxenes and the feldspars.

2. Magmatic alteration of the silicates often takes place prior to the formation of the ore minerals. The most common change is that of pyroxene to hornblende, but easily distinguishable from the hydrothermal process of uralitization.

3. The ores replace the silicate minerals but without reaction rims.

4. The ores are introduced one after another in the following invariable sequence: (1) magnetite and ilmenite, (2) pyrrhotite, (3) pentlandite, (4) chalcopyrite. There is a certain amount of replacement of the earlier ore minerals by the later ones.

5. Hydrothermal alteration is distinctly later than the period of ore deposition.

These data of observation lead them to a theory of genesis more nearly analogous to that of DeLaunay than any of the others mentioned above. The fact that the ore minerals replace the silicates without the formation of metallic silicates by reaction is interpreted to mean that the ores were not introduced in a molten state but that the same agency that brought in the sulphides removed the dissolved silicates, indicating the presence of active mineralizers. The alteration of pyroxene to hornblende is further evidence of the presence of mineralizers. Consequently they conclude that mineralization took place at a temperature below the melting point of the ores and that they were held in solution through the agency of mineralizers. On the other hand, that ore deposition took place under conditions different from those of non-magmatic high temperature deposits is shown by the absence of the secondary silicates characteristic of ordinary pneumatolytic and hydrothermal processes, or that where present they belong to a distinctly later period. They conclude, that the magmatic ores "have been introduced at a late magmatic stage as a result of mineralizers."

The direct evidence presented by Tolman and Rogers is derived from the sulphide deposits, but the presence of a greater or less quantity of titaniferous magnetite in these, and numerous references in the literature to the silicates preceding the ores in order of crystallization in deposits of titaniferous magnetite, led them to infer that the same observations and same conclusions apply equally well to the oxidic ores. My own experience with the titaniferous magnetites corroborates the correctness of this inference. The relations between ore minerals and silicates figured and described for the

sulphide ores are repeatedly duplicated in thin sections and polished sections from all occurrences of titaniferous iron ores in the United States. Titaniferous magnetite later than the silicates and replacing them is seen in nearly every section of the ores, though many of the contacts of the two sets of minerals show what L. C. Graton and D. H. McLaughlin have recently termed *mutual boundaries*, that is, boundaries that give little evidence of the sequence of the minerals. Only rarely is there unmistakable evidence of primary silicates distinctly later than the ore. The replacement of the silicates by the ore has not been accompanied by the formation of reaction silicates and in several instances hornblendization has preceded the deposition of ore, phenomena in harmony with the nature of mineralization in the case of the sulphide ores. If segregation takes place without the intervention of mineralizers, one might expect the deposit at Iron Mountain, Wyoming, to afford such an example. The ore body there occurs as an almost pure mass of titaniferous magnetite cutting the anorthositic country rock as sharply as any igneous dike ever pictured. Yet the numerous olivine crystals which occur locally in the ore are rounded and embayed without the formation of reaction silicates in exactly the same manner as in other occurrences. The deposit suggests an injection from a basic magma analogous to a pegmatite from a more acidic. In other cases, particularly at Grape Creek, Colorado, the introduction of ore has been accompanied by alteration of the feldspar so that the magnetite is separated from it by a band of hornblende, indicating greater than usual activity of mineralizers. The Minnesota deposits conform for the most part to the general rule that the ore is later than the silicates and afford some examples of hornblendization preceding or contemporaneous with ore deposition, but also instances of feldspar and pyroxene later than ore.

An excellent example of an iron ore deposit in a basic igneous rock giving unmistakable evidence of active participation by mineralizers in the formation of the ore is afforded

by the Tofo deposit north of Coquimbo, Chile, being worked by the Bethlehem Steel Company. This consists of a large mass of comparatively pure magnetite forming the top of a hill on the east side of the coast range and occurring within a large area of gabbro rock. The igneous mass has undergone considerable differentiation and various rock types are represented in the vicinity of the ore body from highly feldspathic to almost pure ferromagnesian silicate rocks, some of which occur as dikes. The broader relations of the ore body are such as to suggest at once a magmatic segregation; but, at the same time, there are many features that suggest pneumatolysis. Adjacent to the ore, there are numerous stringers of magnetite in the country rock, many of them of no greater thickness than a knife blade, which traverse it in such a way as to preclude the entrance of molten oxides and that can be explained only on the basis of the high liquidity at lower temperature that would be imparted by the presence of abundant mineralizers.

The argument for the participation of mineralizers in the formation of magmatic deposits is a plausible one also from a general standpoint of ore genesis. Processes in nature representing different stages of a sequence from a given starting point are not usually separated by a hiatus. It is generally accepted today that igneous magmas are the primary sources of the metals and modern genetic classifications group ore deposits according to their position or relation to the original sources. It has been customary, however, to draw a sharp line between one group of deposits which it was held segregated from the molten magma and solidified with it, and such groups as represented deposition of material extracted from the magma by mineralizers and constituting the pneumatolytic and hydrothermal deposits. DeLaunay's classification recognizes no such hiatus in the sequences of mineralization, but postulates a gradually increasing participation of mineralizers and hence a gradual gradation from one stage to the next. It goes even a step further and indi-

cates that concentration of the metallic content of a magma to the extent necessary to form important ore bodies takes place only when the necessary migration of the metals is aided by the presence of mineralizers. For the only group recognized by him in which mineralizers did not participate in ore deposition, his *gîtes d'inclusions*, contain no deposits of economic importance; and it is only in his next group, in which mineralizers begin to play a part, that important ore deposits begin to be represented. There have been two lines of thought seeking to explain ore genesis, the one represented by the French school which has always emphasized the role of mineralizers, and the other by the American and German economic geologists who have tended to draw the sharp line of demarcation between the magmatic deposits and the non-magmatic. The participation of the latter group has so greatly preponderated over that of the former during the last quarter century in the development of the science of economic geology that the views of the French school have often been completely overshadowed and have not received the attention they merit. The monograph by Tolman and Rogers will serve to establish among American economic geologists the ideas embodied in the conceptions of the French school. It is hoped that this survey of the problem and the corroborative evidence contributed in the case of the iron ores will serve the same purpose. One cannot help but feel that a new study of the chrome ores with this interpretation in mind would place them in harmony with it. As their case now stands, they seem to be an exception and to represent a direct segregation as the first product of crystallization from a molten magma.

THE ENVIRONMENT OF THE TERTIARY MARINE FAUNAS OF THE ATLANTIC COASTAL PLAIN

By JULIA A. GARDNER

The Miocene and Pliocene deposits of the Atlantic Coastal Plain have now been mapped in detail from New Jersey to North Carolina and the contained faunas, which are prolific and varied, have been rather fully described.¹

The following formations have been recognized in the Middle Atlantic region:

	<i>Maryland</i>	<i>Virginia</i>	<i>North Carolina</i>
Pliocene:	_____	_____	Waccamaw
	_____	Yorktown	Yorktown-Duplin
Miocene:	{ St. Mary's	St. Mary's	St. Mary's
	{ Choptank		
	{ Calvert	Calvert	

All of these formations contain extensive molluscan faunas and very large collections have been available for study and comparison. An idea of the richness of these faunas may be obtained from the following census of the faunas of the respective formations:

	<i>No. of species</i>	<i>in genera</i>
Waccamaw	325-335	130
Yorktown	364-378	143
Duplin	420-431	154
St. Mary's	326-344	129
Calvert	80-83	50

¹ The more recent literature includes the following:

Whitfield, R. P., *Mon. U. S. Geol. Survey*, vol. xxiv, 1894.

Clark, Martin, Glenn and others, *Miocene vol.*, Md. Geol. Survey, 1904.

Gardner, J. A., "The Miocene and Pliocene Faunas of Virginia and North Carolina," Prof. Paper U. S. Geological Survey. (In press.)

These faunas are exceedingly interesting, not only because of their diversity and the remarkable development of certain groups, but also because of the light they shed on the physical conditions under which they lived. In the following notes, which are based on the study of compiled tables of both recent and fossil forms, an attempt is made to summarize the probable physical conditions indicated by this study.

Any attempt to reconstruct bottom conditions in the ancient seas must of necessity be based upon data so meagre and so inaccurate that any hope of obtaining absolute values is vain, and yet it does seem worth while to occasionally gather the imperfect knowledge available and to try to interpret it. Errors do, to a certain extent, neutralize one another and within certain limits general tendencies and relative values can be given with a very considerable degree of assurance.

Over 800 species have been determined from the Miocene and Pliocene of Virginia and North Carolina and of these approximately 20 per cent. persist into the recent faunas. Certainly a number so large as this ought to give a fairly true line upon general temperature and bathymetric conditions in the middle and later Tertiaries.

It may be well to consider the main sources of error before giving the conclusions which they modify.

A. SOURCES OF ERROR IN THE DATA UPON THE TERTIARY FAUNAS.

1. Errors in determination.

This is one of the least important. The greater part of the work upon the faunas in question has been done by less than half a dozen students and the same collections, for the most part, have been used for reference. Consequently the determinations, whether accurate or inaccurate, are fairly consistent. Furthermore, if two forms are so much alike that there is a question as to their identity, a similarity of environmental conditions is implied, even though the differences may later prove to be specific.

2. A mechanical sorting of the shells.

This is a much more serious error and one which it is impossible to eliminate. One of the most interesting phases of in-shore marine life is the dissimilarity in the dredge hauls within a limited area. The in-shore currents are quite sufficient to materially affect the character of the bottom and the distribution of the algal growth and thus to limit the range of a considerable number of species, particularly the vegetable feeders. Unfortunately, almost all such ecologic variations have been washed away. Not only have near-by but distinct assemblages due to slight differences in environmental conditions been commingled but dead shells have been washed down from the river mouths and up from the off-shores and mixed together in a heterogeneous ensemble. The hard parts of the smaller species, many of which constitute an important item in the diet of various fishes may be carried for indefinite distances beyond their normal habitat before being laid down in their final resting place. In recent faunas extra-limital shells are usually so badly worn that their distant origin may be surmised but in the fossil forms it is much more difficult to isolate them by this method. It is, however, reasonable to suppose that forms occurring in any considerable abundance are indigenous to the fauna but inferences made from the presence of only one or two individuals should be guarded.

B. SOURCES OF ERROR IN THE DATA UPON THE RECENT FAUNAS.

1. Errors in determination.

These are much more frequent in the Recent collections than in the fossil because the work has extended over a much greater time and the personal element is much more conspicuous. However, errors in the determination of the fossils are frequently parallel to those of the Recent faunas so that the final results are not always affected. The tendency in the Recent work is towards an increasingly finer distinction of species so that the ranges are becoming more and more re-

stricted. This is especially true in certain families. In a recent zoögeographic study of the West Coast *Pyramidellidae* 10 faunal zones were differentiated.² The three most populous were the Oregonic with 70 species, the Californic with 164 and the Mazatlanic with 75. However, only 11 species common to the Oregonic and Californic were recognized and only 2 common to the Californic and Mazatlanic. No refined study such as this has ever been made upon any of the East Coast molluscs, but when it is done the number of species will doubtless be greatly increased and their ranges greatly diminished. The fossil forms can then be interpreted in terms of the Recent with an accuracy and a detail far in advance of anything that is possible at present. The knowledge of the Tertiary ecology may approximate the Recent but it can never go beyond it.

2. The limited number of dredging records.

Not only are the stations relatively few in number but they are so grouped that there are long stretches which have not yet been touched. The attempt has been made, however, to cover the critical areas, such as that of the Florida coast, Hatteras and Woods Hole. The New England fauna is well known in a general way and extensive collections have been made through the Gulf and the West Indies by the *Blake* and the *Albatross*. A very short but significant report is that of Bartsch and Henderson upon a two days' collecting trip off Chincoteague Island on the Virginia coast for the purpose of determining the extent of overlap of the southern fauna.³ The latest of the larger reports, that upon the Woods Hole region is by far the most satisfactory excepting that it covers an area so restricted and so little diversified. The arrangement, however, is excellent for an ecologic study, the dead shells are isolated from the living and the young

² Bartsch, P., 1912, *Proc. U. S. National Museum*, vol. 42, p. 299.

³ Bartsch and Henderson, 1914, *Proc. U. S. Nat. Mus.*, vol. 47, pp. 411-421.

from the adult, the number of specimens is given and the data upon depth, temperature, salinity, etc., is complete and accurate. The bathymetric distribution of most of the southern stations is unfortunate for those interested in determining the limits in depth of the littoral fauna. Very little shore dredging has been done and there are very few records from less than 10 fathoms. A number of unusually rich hauls were made off Hatteras between 15 and 25 fathoms. The 49 and 63 fathom stations include in addition to the native fauna a considerable number of young or more or less worn shells referable to the more abundant species in the lesser depths but in the great majority of records these fortuitous shells have not been isolated. However, the general relationships which come out of an interpretation of the recent elements in the fossils faunas are probably true, even though the data upon which the results are based is woefully inadequate.

Five formations have been recognized in the Miocene and Pliocene of Virginia and North Carolina,—the Calvert, St. Mary's and Yorktown in Virginia and the Yorktown, Duplin and Waccamaw in North Carolina. The Yorktown and Duplin were probably, for the most part, synchronous though laid down in separate basins. Approximately 65% of the species common to the Calvert and Recent faunas have been reported from north of Hatteras, the limit of range of many of the northern and of the southern forms; 54% of the St. Mary's; 46% of the Yorktown; 35% of the Duplin, and 36% of the Waccamaw. Factors other than temperature have modified somewhat the figures for the Duplin and Waccamaw, for there is no reason to suppose that the Waccamaw sea was not quite as warm as the Duplin.

The break between the late Oligocene and the early Miocene in the Southern Atlantic states is one of the sharpest in the stratigraphic succession of the Cenozoic. The Oligocene has not been recognized either in Virginia or North Carolina but the early Miocene fauna is similar in general character wherever it occurs along the East Coast. Twenty species

from the Calvert of Virginia, approximately 12½% of the entire fauna, persist into the Recent and furnish consistent evidence of environmental conditions during Calvert Times. The depth of the waters in which they live did not, in all probability, exceed 20 or 25 fathoms. The temperature was perceptibly lower than that of any other of the middle or late Tertiary faunas of that region. The bottom was probably soft, dominantly mud, with a mixture of sand. At least a portion of the shore must have been sufficiently sheltered to encourage the growth of kelp and sea lettuce and other sea weeds to which many of the smaller univalves and bivalves characteristically attach themselves. The Calvert of Maryland is unusually varied for the latitude. It is quite possible that the ancient shore line in that area was fringed with islands and sand spits similar to those along the outer margin of Virginia and North Carolina today and that during Calvert times the spits were now washed away, admitting the off-shore fauna, and now built up, protecting the waters behind them and allowing a warmer water element to creep in and establish itself.

There is no evidence of any marked change in the ecology in passing from the Calvert to the St. Mary's. All of the recent species represented in the Calvert are present in the St. Mary's but the number is almost tripled. The northern element, however, is slightly less prominent and the southern element a little more so. The fauna is prolific in individuals but not greatly diversified. The outstanding differences between the St. Mary's molluscs of Maryland and those of Virginia and North Carolina are mainly those of latitude, although the presence in Maryland of a considerable number of *Surculus*, one of the characteristically deep-water pleurotomids suggests deeper water in that area. The faunas in Virginia and North Carolina are remarkably uniform. There are, to be sure, a few species common to Maryland and northern Virginia which are not found in North Carolina and a few of southern affinities which are restricted to North Carolina. The monotony of the assemblage indicates a long

stretch of open shore with only an occasional bight from the vicinity of the present York River in Virginia to that of the Neuse River in North Carolina. The slope of the continental shelf must have been very gentle, not more than 3' to the mile, since there is no perceptible change in the bathymetric character of the fauna between the extreme eastern and western outcrops, a distance of 60 or 70 miles. There is no reason to believe that any part of this platform was submerged to a depth of more than 30 or 40 fathoms. The bottom was doubtless soft and, for the most part, muddy since the mud-burrowers, notably *Mulinia* are exceedingly prolific and widely distributed. The waters must have been sufficiently clear, however, and the bottom sufficiently shelly to furnish clutch for the numerous oyster spat and to permit them to mature. Conditions were probably not very favorable to algal growth, since most of the groups which characteristically attach themselves to the sea-weeds of various kinds have a meagre representation.

The elevation along the Hatteras axis at the close of the St. Mary's was apparently great enough to cut off the Yorktown basin in Virginia from the Duplin in southern North Carolina. The faunas of the two basins, though similar in general character, differ more in detail than one would expect in two shallow water faunas only a couple of hundred miles apart. The contemporaneity of the Yorktown and Duplin faunas was suggested by Dr. Dall more than fifteen years ago and even at that time he brought forward in explanation of the conspicuous faunal differences the potency of the ocean currents, a factor which has been so emphasized of late in the distributional studies upon the West Coast. The Yorktown fauna is strikingly like that listed by Bartsch and Henderson from Chincoteague Bay, Accomac County, Virginia. The greatest break in the East Coast life from the late Tertiary on to the Recent comes at Hatteras, the point at which the Gulf stream leaves the inshore and swings out toward the open sea. Many of the sub-tropical species are able to follow along the shore as far as it is protected by the warm current, which

also serves as an effective barrier to most of the northern forms. At Chincoteague, Bartsch and Henderson found that while along the ocean side of Chincoteague Island the fauna was consistently northern in its affinities, in the protected inner bight there was an overlap of the southern faunas. Twenty-eight of the 70 species which they have listed are present in the Yorktown fauna and the number of common forms will doubtless be greatly increased with further investigations. The ensemble of the fossil and Recent faunas is conspicuously similar although the southern element is a little stronger in the former. However, much the same conditions of sandy shores and muddy bogs more or less choked with algal growth obtained in the Yorktown as along the Virginia coast today. The fauna, like those that precede and those that follow it, is characteristically shallow water and it is doubtful if any of the indigenous species lived at a depth of more than 25 fathoms.

The Duplin fauna is less homogeneous. Mingled with the large pleurotomid element and a considerable number of volutoids, one of the most uniformly deep-water families, are nine species of *Ilyanassa*, a group that is known to occur only along inter-tidal beaches. The sediments of the Duplin are, for the most part, coarse sands. It seems on the whole reasonable to suppose that the native Duplin fauna lived near the mouth of some rather large estuary and that the streams entering the bay brought down in considerable numbers the beach-dwellers from farther up shore, while strong currents from the south sweeping along the mouth of the estuary contributed not only a southern element of living forms but also a large number of dead shells referable to extra-limital species. One hundred and thirteen Duplin species are either identical with the Recent forms or so closely allied that they have been confused in the synonymies. Of this number 97, approximately 85%, occur between Hatteras and Florida. Of the remaining 18 only a single species, the rather uncommon *Polynices heros*, does not range as far south as Hatteras. Most of the characteristic Florida elements, however, are

absent, so that it seems probable that Duplin temperature conditions are more nearly duplicated between Cape Fear and Charleston, South Carolina, than along any other section of the Coast.

In the succeeding Waccamaw the conditions of the Duplin were some of them intensified but not materially changed. The fauna is, on the whole, more consistent, for both the brackish and the deep water elements are rather less pronounced. There were, judging by the abundance of such forms as the *Olivas* and *Olivellas*, extensive sand flats covered by from 2 to 10 fathoms of water, while the wealth of *Bittiums* and small *Cerites* and other groups of similar habits demands conditions favorable for extensive algal growth. There is a curious similarity in the general make-up of the Waccamaw and Yorktown faunas, due, doubtless to the similarity in ecology. The Waccamaw waters, however, were decidedly warmer than those of the Yorktown, in fact they were in all probability warmer than at any other period during the middle or late Tertiaries or than those off North Carolina today. The evolution toward the Recent Cape Fear fauna has been marked less by the introduction of a northern element than by the restriction of the more sensitive southern forms to the Floridian province.

THE PELECYPODS OF THE BOWDEN FAUNA

By WENDELL P. WOODRING

1. INTRODUCTION

The marls exposed along the coast between Morant Bay and Port Morant, near Bowden, almost at the southeastern extremity of the island of Jamaica, have long been known to contain a prolific and splendidly preserved molluscan fauna. In 1862 Mr. Lucas Barrett, the Director of the Jamaican Survey, deposited in the British Museum a collection apparently from this locality. A year later Mr. Carrick T.

Moore² submitted a brief report on the mollusca. The first systematic account of the fauna was published in 1866 by the late Mr. R. J. Lechmere Guppy,³ who later made several additional contributions.⁴ Mr. Robert Etheridge⁵ in an appendix to the report of the *Jamaican Survey*, published in 1869, discussed the general aspect of the fauna. In 1896 Guppy and Dall⁶ issued descriptions of a number of new species. The report of Mr. Robert T. Hill⁷ on his reconnaissance of Jamaica contained a brief notice of the molluscan elements of the fauna. In the *Wagner Institute Papers* Dr. Dall⁸ described many new species and noted the occurrence of previously described forms; in addition, the last fascicle contained a discussion of the correlation of the fauna and a check-list.⁹

2. BIOLOGICAL CHARACTER OF THE FAUNA

The present study has resulted in the recognition of between 190 and 200 species of pelecypods, of which almost half are new. These are segregated into 64 genera and 40 families. The superspecific groups and the number of species in each group are given in the following list:

² Moore, C. T., *Quart. Jour. Geol. Soc.*, London, vol. 19, pp. 510-513, 1863.

³ Guppy, R. J. L., *Quart. Jour. Geol. Soc.*, London, vol. 22, pp. 281-295, 1866.

⁴ Guppy, R. J. L., *Geol. Mag.*, decade v, vol. 4, pp. 496-501, 1867; *idem*, decade 2, vol. 1, pp. 404-411; 436-446, 1874; *idem*, vol. 2, pp. 41-42, 1875; *Proc. Assoc. Trinidad*.

⁵ Etheridge, R., *Reports on the Geology of Jamaica*, Part 2, West Indian Survey, Mem. Geol. Survey Great Britain, ap. 5, pp. 319-329, 1869.

⁶ Guppy, R. J. L., and Dall, W. H., *Proc. U. S. Nat. Mus.*, vol. 19, no. 1110, pp. 303-331, 1896.

⁷ Hill, R. T., *Bull. Mus. Compt. Zool.*, Harvard, vol. 34 (geol. ser. 4), pp. 145-152, 1899.

⁸ Dall, W. H., *Trans. Wagner Free Inst. Sci.*, Philadelphia, vol. 3, pts. 1-6, 1890-1903.

⁹ *Idem.*, pt. 6, pp. 1580-1588, 1903.

- Nucula 2 pp.
- Leda 7 spp.
- Yoldia 1 spp.
- Tindaria 1 spp.
- Limopsis 2 spp.
- Arca (Arca s. s.) 4 spp.
 - Barbatta (Acar) 2 spp.
 - (Calloarca) 4 spp.
 - (new section) 3 spp.
 - (Fossularca) 2 spp.
 - Scapharca (Scapharca s. s.) 9 spp.
 - (Argina) 1 sp.
 - (Cunearca) 1 sp.
 - (Bathyarca) 1 sp.
 - (Anadara) 1 sp.
- Glycymeris 3 spp.
- Pinna 1 sp.
- Atrina 1 sp.
- Melina 1 sp.
- Pteria 1 sp.
- Ostrea 3 spp.
- Pecten
 - Pecten (Pecten s. s.) 1 sp.
 - (Euvola) 2 spp.
 - Chlamys (Chlamys s. s.) 4 spp.
 - (Aequipecten) 5 spp.
 - Pseudamysium (Pseudamysium s. s.) 1 sp.
 - Amysium (Amysium s. s.) 1 sp.
 - (Propeamusium) 1 sp.
- Spondylus 3 spp.
- Plicatula 1 sp.
- Lima (Lima s. s.) 1 sp.
 - Lima (Mantellum) 1 sp.
- Limæa 1 sp.
- Placuanomia 1 sp.
- Anomia 2 spp.
- Modiolus (Brachydontes) 1 sp.
- Dreissena 1 sp.
- Julia 1 sp.
- Verticordia (Trigonulina) 1 sp.
 - (Haliris) 1 sp.
- Poromya 1 sp.
- Cuspidaria (Cardiomya) 1 sp.
 - (Bowdenia) 1 sp.
- Crassatellites (Crassatellites s. s.) 2 spp.
 - (Crassinella) 3 spp.
- Venericardia (Venericardia s. s.) 1 sp.
 - (Pteromeris) 1 sp.
- Chama 2 spp.
- Echinochama 1 sp.
- Codakia (Codakia s. s.) 2 spp.
 - (Jagonia) 3 spp.
- Myrtæa (Myrtæa s. s.) s spp.
 - (Eulopia) 3 spp.
- Phacoides (Phacoides s. s.) 1 spp.
 - Here (Here s. s.) 4 spp.
 - (Pleurohucina) 1 sp.
 - (Cavilucina) 1 sp.

- Pseudomiltha 1 sp.
- Callucina 3 spp.
- Parvilucina (Parvilucina s. s.) 3 spp.
(Bellucina) 2 spp.
- Divaricella 2 spp.
- Diplodonta (Diplodonta s. s.) 2 spp.
(Pelaniella) 1 sp.
(Phlyctiderma) 1 sp.
- Erycina 2 spp.
- Anisodonta (Basterotia) 1 sp.
- Montacuta? 1 sp.
- Cardium (Cardium s. s.) 1 sp.
Trachycardium 4 spp.
Fragum (Fragum s. s.) 2 spp.
(Trigoniocardia) 3 spp.
- Laevicardium 1 sp.
- Protocardia 2 spp.
- Transennella 2 spp.
- Tivela 1 sp.
- Gafrarium (Gouldia) 1 sp.
- Pitaria (Hyphantosoma) 1 sp.
(Lamelliconcha) 1 sp.
- Antigona (Ventricola) 1 sp.
- Cyclinella 1 sp.
- Chione (Chione s. s.) 3 spp.
Chione (Lirophora) 1 sp.
- Parastarte 1 sp.
- Cooperella (new section) 1 sp.
- Tellina
 - Arcopagia (Merisca) 4 spp.
(Phyllodina) 2 spp.
(Eurytellina) 1 sp.
 - Moerella 2 spp.
 - Angulus (Angulus s. s.) 5 spp.
(Scissula) 1 sp.
- Strigilla 1 sp.
- Macoma
 - Psammacoma (Psammacoma s. s.) 2 spp.
 - Cymatoica 1 sp.
- Semele (Semele s. s.) 1 sp.
- Abra 2 spp.
- Donax 2 spp.
- Psammosolen 1 sp.
- Spisula 1 sp.
- Ervilia 1 sp.
- Corbula (Aloidis) 1 sp.
(Cuneocorbula) 1 sp.
(Bothrocorbula) 1 sp.
- Gastrochaena 1 sp.
- Martesia? 1 sp.
- Xylophaga? 1 sp.
- Teredina 1 sp.
- Teredo 1 sp.¹⁰

¹⁰ An additional form is considered the type of a new genus of doubtful affinities placed provisionally among the Isocardiacea, probably near the Vesicomycidas.

The Prionodesmacea play an important rôle in the constitution, being represented by 79 species, or more than 40 per cent of the fauna. The larger part of this number is contributed by the taxodonts, which include 44 species. The most abundant taxodont is the genus *Arca*, which has 28 species distributed among 10 sections. The Scapharcas are the most prolific, both individually and specifically. The section Cunearca, which usually occupies a position of importance in the mid-Tertiary faunas of the Antillean region and its perimeters, is represented by a single small form and the subgenus *Noëtia* is entirely absent. Three species of *Barbatia* are grouped in a new section that bears a relation to *Barbatia* s. s. similar to the relation between *Argina* and *Scapharca* s. s. Another *Barbatia* of unusual type has been provisionally referred to *Fossularca*, although it probably represents a new section. A minute *Bathyarca* is abundant in one of the collections, but is rather rare in the other minute collections available.

Among the prionodonts the Pectens are subordinate only to the Arcas. They contribute 15 species representing seven sections among which are included virtually all the groups of a typical tropical fauna. The Aequipectens are the most abundant and include several species that are widely distributed in the Tertiary deposits of the Antillean region. With regard to specific diversification *Chlamys* s. s. is comparable to Aequipecten, but only one of the species is abundant. The valves of a small delicate *Pseudamusium* s. s. are numerous and the section *Propeamusium* is represented by a single valve.

The oysters form a puzzling assemblage. In all the collections the number of individuals is small and large forms are notably absent. The small size is probably not without significance when it is considered that one of the Bowden species reaches an imposing size in the Alum Bluff faunas and especially in the Santo Domingan fauna. A similar relation obtains for an unusually large and ponderous Santo Domingan *Spondylus*. If the current synonymy for *Ostrea*

megodon Hanley is accepted, this species furnishes an example of a former distribution on both sides of the Isthmus of Panama and a present restriction to the Pacific side. Another oyster probably is identical with the Recent mangrove-oyster, *O. folium* Linnaeus. Although the species may not be genetically valid, it may be assumed that the Bowden form had the peculiar habits of the oyster that is frequently found in mangrove swamps in the Antillean region.

The family Limidae includes, in addition to the common *Lima*, the rare *Limæa*. Likewise among the Anomindae is found the uncommon *Placunanomia*, as well as the ubiquitous *Anomia*. The brackish-water *Dreissena* is not frequently encountered among American Tertiary faunas. Of greater interest is the presence of the extremely rare *Julia*, a genus that at the present time is confined to the Indo-Pacific region and is represented by only a few fossil species—one from the Oligocene of Florida and two from the Miocene of southwestern France.

A minor element in the fauna is furnished by the Anomalo-desmacea. The five species are confined to the superfamily Poromyacea and include small forms under the families Verticordiidae, Poromyacidae and Cuspidariidae. One of the Cuspidarias is the type of the subgenus *Bowdenia* Dall.

The relative importance of the Teleodesmacea is diminished by the unusually large number of prionodonts, although naturally the teleodonts include the bulk of the fauna. Among the Astartacea members of the family Astartidae are conspicuously absent, but the Crassatellitidae are represented by five species of *Crassatellites*, of which the most important and the most abundant belong to the subgenus *Crassinella*. No Carditas are present, but the genus *Venericardia* includes a prolific *Venericardia* s. s. and also a small curious form that has been referred to the subgenus *Pteromeris*, although it is hardly typical of that group.

The superfamily Lucinacea is the most diversified of the larger groups. Although only five genera are included, they are represented by 32 species. The genus *Phacoides* alone

furnishes half of the species distributed among eight sections. Two phacoidean elements, *Lucinisca* and *Miltha*, as well as the genus *Lucina*, are absent. The Codakias and Myrtaeas are abundant and well-developed. The Divaricellas are individually numerous, whereas the Diplodontas are, as usual, represented by a small number of individuals.

In contrast to the richness of the lucinoids is the meager representation of the Leptonacea. The entire superfamily includes but four species segregated into three genera and as many families. Furthermore, the four species are represented by only six valves, two of which belong to the rarely encountered subgenus *Basterotia* of the genus *Anisodonta*.

Among the larger groups is the genus *Cardium*, represented by seven sections and eleven species. The sections are such as are found in any tropical or sub-tropical mid-Tertiary American fauna, but *Cerastoderma* and *Papyridea* are not included. The Trigoniocardias, which are peculiar to the mid-American region, are a conspicuous element; indeed, a species of this section is the most abundant bivalve in the fauna.

The eight veneroid genera are divided among the subfamilies Meretricinae, Venerinae and Geminae. *Chione* is the most abundant with regard to both the number of species and individuals. *Parastarte*, represented by a single valve, has heretofore not been reported outside of the Floridian region either recent or fossil. The genus *Tivela* is not included in any of the Tertiary faunas of the North American mainland. An interesting form comparable to *Cooperella* in dentition is placed in a new section of that genus. Only two species of *Cooperella* are known, a Recent species from the west coast of North America and another from the late Miocene of the Atlantic Coast.

The genus *Tellina* includes 15 species, distributed among 6 sections. *Angulus* has the largest number of species, but the most abundant forms are found under *Merisca* and *Moerella*. Among the Macomas is a typical *Cymatoica*. The remaining Teleodesmacea are scattered among several groups.

A single fragmentary valve of an indeterminable *Spisula* is the sole representative of the Mactridae. Two of the three species of *Corbula*, the only non-boring Myacea, are exceedingly abundant. The unusually favorable conditions of preservation are indicated by the presence of several fragile boring Adesmacea.

3. PHYSICAL CONDITIONS

The student of recent marine faunas would consider with undisguised suspicion an attempt to reconstruct environmental conditions on the basis of the testimony furnished by a single element in a fauna. Despite the lack of an intensive census of a restricted shallow-water West Indian area, which would be of inestimable value in projecting backward the factors that determined the assemblage of an Antillean Tertiary fauna, the ensemble of Bowden pelecypods is such as to permit the offering of certain considerations, some of which are more or less obvious and even trite.

Though it is a mere platitude to state that the fauna is tropical, yet this facies is emphasized in a striking manner by the development of certain groups and the absence of others that are prominent in the Tertiary faunas of the southern Atlantic Coast. The most prolific genera—*Arca*, *Pecten*, *Phacoides*, *Cardium*, *Tellina*—are characteristically tropical or are represented only by sections or species that are confined to low latitudes or there reach their maximum development. According to the latest faunal lists only two of the 18 species that persist to the Recent at present range north of Cape Hatteras—the ubiquitous *Anomia simplex* d'Orbigny and *Divaricella quadrisulcata* (d'Orbigny). Eight are recorded from Hatteras southward to the West Indies or Brazil; seven are confined to the area south of Florida and one species is restricted to the tropical portion of the West Coast. Virtually the same proportions obtain for a large number of Recent species that closely resemble Bowden forms.

The Arcas reach their greatest importance in the warmer

seas. The Bowden species are such as would be expected in tropical waters; indeed a number of them are encountered in the present West Indian fauna. The genus *Pecten* is usually a conspicuous element in the Tertiary and Recent faunas of all latitudes, but the large species that are characteristic of higher latitudes, are absent. *Spondylus* is confined to tropical or sub-tropic regions in the Recent seas. In the middle and late Tertiary faunas of the United States the genus is restricted to rare occurrences in the Floridian region. Perhaps the most obvious indication of the temperature of the waters is furnished by the superfamily *Astartacea*, which is represented only by several *Crassatellites*. Even the warm-water Caloosahatchie and Waccamaw faunas include one or two *Astartes*, but in the Bowden assemblage the genus is entirely absent. An *Echinochama*, a genus which is preëminently Antillean, is the most ponderous bivalve in the fauna. The entire group of lucinoids is quite partial to tropical waters, although a few species, especially of the genus *Divaricella*, range into high latitudes. By far the greater number of the *Cardiums* are of the ornate type that indicates a warm-water habitat. Moreover, the smooth or relatively simple forms are identical with, or closely related to, Recent species that do not occur north of Florida. Although the distribution of the genus *Tellina* is almost world-wide the group is predominantly tropical.

In attempting to determine the depth of the water from a consideration of the bathymetric range of identical or closely related Recent species a rigid adherence to the evidence furnished by dredging records would often lead to absurd conclusions. An example is furnished by the genus *Limopsis*, of which two species are present. According to available data the group as a whole is characteristic of deeper water, yet several species occur in Eocene beds of the Gulf Coast that undoubtedly were deposited in very shallow water.

The fauna is essentially a shallow-water fauna. All of the Recent species occur in water of shallow depth and many have been recorded from the intertidal zone, but the range of sev-

eral is extended into considerably deeper water. The presence of apparently deeper water elements, such as *Tindaria* and *Bathyarca*, may be the result of the action of currents or other extra-limital factors. Since but a single valve of *Tindaria* is present it is doubtful whether the form was indigenous. It may be suggested that the depth did not exceed 30 or 40 fathoms and it is highly probable that the bulk of the fauna lived in water that was considerably shallower.

The waters were clear and the bottoms free from mud. By far the larger number of the Bowden pelecypods are partial to bottoms of sand or fine gravel; even the burrowers are usually found on sandy bottoms. The absence of *Mulinia* and related forms that prefer a muddy bottom is not without significance. The meager representation or absence of the Leptonacea and other small forms that usually frequent muddy bottoms in sheltered near-shore positions or are attached to algae indicates an open coast and rather strong current action. Estuaries interrupted the coast line and led back to the streams that supplied the relatively coarse volcanic debris which constituted the bulk of the sediments. From the estuaries valves of *Dreissena* and the mangrove-oyster were carried down to the coast and mixed with the indigenous beach and off-shore dwellers.

4. RELATIONS TO THE FAUNAS OF THE NORTH AMERICAN MAINLAND

The possibility of comparing an Antillean Tertiary fauna with those of the Floridian Peninsula is enhanced by the proximity of the areas and by the succession of tropical or sub-tropical faunas of the mainland. Dall¹¹ has correlated the Bowden horizon with the top of the Alum Bluff formation which includes the Chipola, Oak Grove and Shoal River members in ascending order. According to Dall¹² the Chipola

¹¹ Dall, W. H., Trans. Wagner Free Inst. Sci., Philadelphia, vol. 3, pt. 6, pp. 1560, 1582, 1903; *Bull. U. S. Nat. Mus.* 90, p. 8, 1916.

¹² Dall, W. H., *loc. cit.*, p. 1574, 1903.

fauna indicates distinctly sub-tropical conditions. Berry¹³ has shown that the Alum Bluff flora is sub-tropical or very warm temperate and according to Dall¹⁴ the Oak Grove fauna indicates a slight lowering of temperature. Above the Alum Bluff formation is a sharp break that has been seized upon as a convenient location for the division between the Oligocene and Miocene. Though the succeeding Miocene faunas of Florida are imperfectly known they unquestionably indicate a more temperate facies¹⁵ and occupy a position near the middle of the Miocene series of Virginia and the Carolinas. The Pliocene Caloosahatchie formation of Florida has yielded a rich sub-tropical fauna.

The profound hiatus in the Floridian succession is partially bridged by the Miocene deposits of Virginia and the Carolinas. According to Berry¹⁶ the Calvert formation, which is the oldest, is middle Miocene, probably Tortonian. The only faunas of this region that present a warm-water facies are those of the late Miocene Duplin and the succeeding Pliocene Waccamaw, both of which are warm temperate rather than sub-tropical. It is apparent that an attempt to compare a mid-Tertiary Antillean fauna with the faunas of Florida is seriously hampered by the absence of any tropical or sub-tropical Miocene faunas on the mainland. Furthermore, in order to make comparisons with any warm-water Miocene fauna of the Atlantic Coast it is necessary to resort to the geographically distant warm temperate Duplin fauna. In Florida the only post-Alum Bluff marine assemblage that flourished under conditions in any manner comparable to those of an Antillean fauna is the sub-tropical Pliocene Caloosahatchie fauna, which is appreciably younger than the slightly more temperate Waccamaw fauna.

¹³ Berry, E. W., U. S. Geol. Survey Prof., Paper 98-E, pp. 43-44, 1916.

¹⁴ Dall, W. H., *loc. cit.*, pp. 1549, 1581, 1588-1589, 1903.

¹⁵ Dall, W. H., *loc. cit.*, pp. 1549, 1589, 1594, 1903.

¹⁶ Berry, E. W., U. S. Geol. Survey Prof., Paper 98-F, p. 66, 1916.

The Chipola marl among the Florida horizons has the largest number of species in common with the Bowden. The actual number is of little significance since the Caloosahatchie has almost the same number. It is significant, however, that the Chipolan elements are completely overshadowed by the closer affinities of a large number of groups with Duplin and even Waccamaw and Caloosahatchie forms. Difficulties are encountered in interpreting these modern elements in terms of age relations to the faunas of the mainland, since obviously considerations of facies and geographical proximity are involved. A larger number of Bowden species are found in the present West Indian waters than in any of the Florida Tertiary faunas and more forms are common to the Caloosahatchie than to the Oak Grove, Duplin or Waccamaw.

The taxodonts supply one-third of the total number of Recent species and all of these are found among the Arcidae, hence that family, and especially the sub-family Arcinae, has a modern aspect. Five Recent Arcas are included in the list and several others are very closely allied to Recent forms. Four of the Arcas that persist to the Recent are found in the Chipola fauna and three in the older Tampa, so that the actual number is of little weight. But a modern element is furnished by the introduction of the section *Bathyarca*. Two of the three oysters are believed to be identical with Recent species. Among the Pectens are several elements that are not encountered among the Oliocene faunas of Florida; these include an *Euvola* of modern aspect, several *Acquiptens* that are most closely related to Pliocene or Recent forms and a *Propeamusium* of decidedly modern type. Among the remaining *Prionodesmacea* the genera *Limæa* and *Placuanomia* are unrepresented in the Oligocene of the Florida section.

A *Crassinella* strongly suggests a Duplin and Waccamaw species. Aside from a Recent *Chama*, the presence of the genus *Echinochama* lends to the Chamidae a modern appearance. The Lucinacea as a whole present a modern aspect. In addition to several species that are more closely related to

Duplin or later forms, this relation is emphasized by the initial appearance of the section Pleurolucina of the genus *Phacoides*. Although the section Eulopia of *Myrtaea* has been reported from the Tampa fauna, it reaches its earliest development of any importance in the Bowden fauna and is not present in any of the post-Tampa Florida deposits. A peculiar *Here* represents a type that has not been recognized except in the Recent seas and typical Bellucinas have not been reported from horizons lower than the Duplin. The superfamily under discussion includes a Recent *Divaricella* and also a Recent *Diplodonta*, which is unknown from any intervening horizon. Two Recent Cardiums, a *Fragum* and a *Laevicardium*, are confined to Miocene and later horizons on the mainland, and *Trachycardium* includes a type unknown from beds earlier than Pliocene. The Veneridae supply a quota of later Tertiary elements. The Bowden *Tivela* is the only representative of the genus recorded from American Tertiary deposits and a Recent species of *Gafrarium* (*Gouldia*) has not been recognized at any other Tertiary horizon. The single *Cyclinella* is very close to a Recent species and the most abundant *Chione* s. s. is allied to a Duplin form. The genus *Parastarte*, unrecorded from a pre-Miocene horizon, is represented by a species scarcely distinguishable from the Miocene to Recent type of the genus. Among the Tellinacea are to be noted a Recent *Strigilla*, a *Semele* that is surprisingly close to a Pliocene and Recent form and the initial appearance of the subgenus *Cymatoica* of the genus *Macoma*.

Though many of the post-Chipolan elements are found among the characteristically tropical groups, yet the introduction of super-specific groups, some of which are not exclusively tropical, can hardly be disregarded. The Bowden pelecypods are distinctly younger than those of the Alum Bluff faunas, as those faunas are now known. It may be suggested that the Bowden fauna is Burdigalian, that is, Lower Miocene in the sense of most American stratigraphers.

ORIGIN OF THE NATURAL BRINES OF OIL FIELDS

By FRANK REEVES

The origin of the concentrated brines so universally found in oil-bearing strata and other porous, unmetamorphosed rocks lying at depths below the zone of active circulating ground water has never been definitely established. By some these waters are thought to be of meteoric or surface origin, *i. e.*, they are rain waters which have in passing downward through the strata dissolved out of the rock material the salts which they now hold in solution. Others consider them to be the sea water which has remained in the pores of the strata ever since their deposition.

A study of the occurrence and chemical nature of the brines found in the oil sands of southwestern Pennsylvania and West Virginia furnishes data which indicate that the waters in this area are connate or of ocean origin. This conclusion is based on the following lines of evidence:

(1) The distribution of the water suggests that it is not of meteoric origin.

(2) There are no adequate explanations of how the water of deposition has been removed from the strata.

(3) The association of the dry sands and "red beds" of the area indicate that the water present accumulated with the sediments as they were being deposited.

(4) The chemical nature of the brine points to it being of connate origin.

THE DISTRIBUTION OF WATER

In order to consider this phase of the evidence it will be necessary to describe briefly the structural and stratigraphic features of the area under discussion.

Structure of the Area.—The brines occur in the Carboniferous and Devonian strata of the Appalachian coal basin.

This is a shallow geosyncline in which the surface rocks are chiefly of Pennsylvanian age except where in the center of the basin there are from 800 to 1300 feet of Permian strata overlying the Pennsylvanian. In this area the Mississippian and Devonian rocks underly the surface at from 1600 to 2000 feet and 2200 to 3000 feet, respectively. Around the rim of the basin these strata outcrop. On the east they reach the surface along the Alleghany front and on the west in central Ohio. The distance across the center of the basin from outcrop to outcrop of the Devonian strata is about 180 miles. The difference in elevation between the highest and lowest point which the same strata attain is about 8000 feet. Thus it is apparent that the geosyncline is to be considered as a very shallow basin. Across the basin and paralleling the Appalachian mountain folds, the strata are folded into a series of minor anticlines and synclines. Towards the eastern outcrop these flexures become more and more pronounced. In this area the dip along the flank of the folds is about 200 feet to the mile, while in the central part of the basin it seldom exceeds 75 feet to the mile. Westward the folds die out almost entirely and the strata rise to the surface in central Ohio at the rate of about 30 feet to the mile. The strata under consideration therefore are comparatively little folded and consequently little metamorphosed. Faulting is also absent except for a minor fault of a few miles in extent in central West Virginia. Southward across Kentucky and Tennessee the basin narrows and the strata are folded and faulted to a greater degree. On this account and also because of the lack of data on the deep underground waters of the area that part of the basin is not included in this discussion. The northern end of the basin is also not considered here because in that area meteoric water has entered, through old abandoned oil wells, the deeper sands and destroyed more or less the original water content of these strata.

Stratigraphy of the Area.—The drill has penetrated strata from the Permian to the Lower Devonian in the search of oil in the central part of the basin. The Permian and Penn-

sylvanian are the surface rocks. They comprise a series of from 2000 to 2500 feet of alternating thin-bedded shales, sandstones, limestones, clays, and coals. The Mississippian underlies the Pennsylvanian unconformably. It is made up of about 800 feet of sandstone, shales, and limestones which vary in thickness from 100 to 250 feet. The Catskill formation is a non-marine facies of the Upper Devonian. It consists of from 500 to 800 feet of thin-bedded sandstones and red and dark-colored shales. Below the Catskill occur about 3000 feet of compact shales. Underlying these are the Lower Devonian limestones.

Occurrence of the Water.—Water is found in the sandstone and limestone members of the above stratigraphic series. In these it occurs in porous layers in which also occur oil and gas. Usually there is a structural arrangement of these materials. Generally the water occupies the synclines, the gas the anticlines, and the oil intermediate structural positions. This distribution is modified by the amount of water in the sands. Where they are saturated the oil occupies the anticlinal areas. In the Appalachian oil fields, however, the most common condition encountered is where there is but sufficient water to fill up the synclines. The oil, under such conditions, occupies a belt structurally higher and the gas fills up the anticlinal areas. In sands that contain no water the oil is found in the synclines.

The amount of water in a sand is usually thought to be a function of its depth. In general it may be stated that the Pennsylvanian sands are saturated, the Mississippian sands semisaturated, and the Catskill sands dry. This would appear to support the idea that the water present is meteoric in origin. On examining the facts, however, this assumption does not appear to be justified for the water does not disappear with depth. Two deep wells which have penetrated the Lower Devonian strata have revealed the fact that below the dry Catskill sands are prolific water-bearing strata at depths from 5000 to 6000 feet. This occurrence, as well as the universal appearance of water at all depths in other oil fields, indicates

that depth is not a factor in the disappearance of water. This being so, then the usual argument that the water present has originated from descending waters loses weight. The presence of nonwater bearing sands such as the Catskill occurring between saturated strata goes to show that there has been no downward movement of meteoric water across the strata. Thus, on the assumption that the water present has a surface origin it must, then, have reached its present position by entering the strata at their outcrop. This undoubtedly explains the source of the waters occurring in strata of Pennsylvanian age, for these are saturated up to their outcrops with water obviously of surface origin. But the saline waters in the Mississippi sandstones are not present towards their eastern outcrop. The synclines along the eastern flank of the basin contain no water and these would have to be filled before water could reach areas in the sands west of them. It is impossible that the water could have come from the westward for some of the sands, *i. e.*, the Maxton and Hundred-foot sands, are not continuous to the western outcrop of the formations. Thus with these facts opposing the possibility of a vertical or lateral movement of the water it must be considered to be of connate origin.

METHOD OF REMOVAL OF WATER OF DEPOSITION

The processes usually suggested by which the sediments have been depleted of the water deposited with them are hydration, consolidation of the sediments, expansion and evaporation of the water due to heat, and drainage resulting from elevation.

A brief consideration of these hypotheses is sufficient to prove their ineffectiveness.

Hydration cannot have been a factor in the removal of the water for the few minerals of sedimentary strata capable of combining with water would more likely be hydrated while they were accumulating as water-borne sediments than while they were subjected to the heat and pressure incident to their condition of deeply buried strata.

Consolidation of sediments though effective in lowering the amount of pore space does not remove the water from the porous area that remains after consolidation, so such an action tends to increase rather than decrease the per cent. of saturation of the total porosity of the rocks.

The influence of heat resulting from the expansion and contraction following periods of burial and exposure due to erosion can be no effective agent in removing the water since water increases only 4 per cent in volume when it is raised from a temperature of 4 degrees Centigrade to 100 degrees Centigrade and this represents a much greater change in temperature of rock strata than ever occurs in a geologic cycle.

Drainage in an area of the nature of the Alleghany coal basin is not possible since the basin is so shaped that the water cannot drain out of it. Moreover, these sands are below sea level and hence not subject to drainage.

Thus with no adequate explanation of how sea water has been removed from rock strata it is more logical to consider the water present to be of connate rather than of meteoric origin.

THE ASSOCIATION OF THE DRY SANDS AND "RED BEDS"

A study of the non-water-bearing strata of the Appalachian oil fields has furnished data which is to be interpreted as furnishing positive evidence that the waters present in these sands are connate in origin. As mentioned above the Catskill and certain areas of the Mississippian sands contain no water. This absence of water is not due to structural or porosity conditions but it is characteristic of sands which are associated with red shales. Several lines of evidence indicate that these dry areas and the "red beds" were developed when the sediments were exposed as flood-plain deposits to the action of air which oxidized the ferrous minerals present and at the same time dried out the sediments, in which condition they have remained to the present time. The acceptance of this conclusion, the arguments in support of which are given

elsewhere,¹ results in attributing a connate origin to the water present.

THE CHEMICAL NATURE OF THE WATER

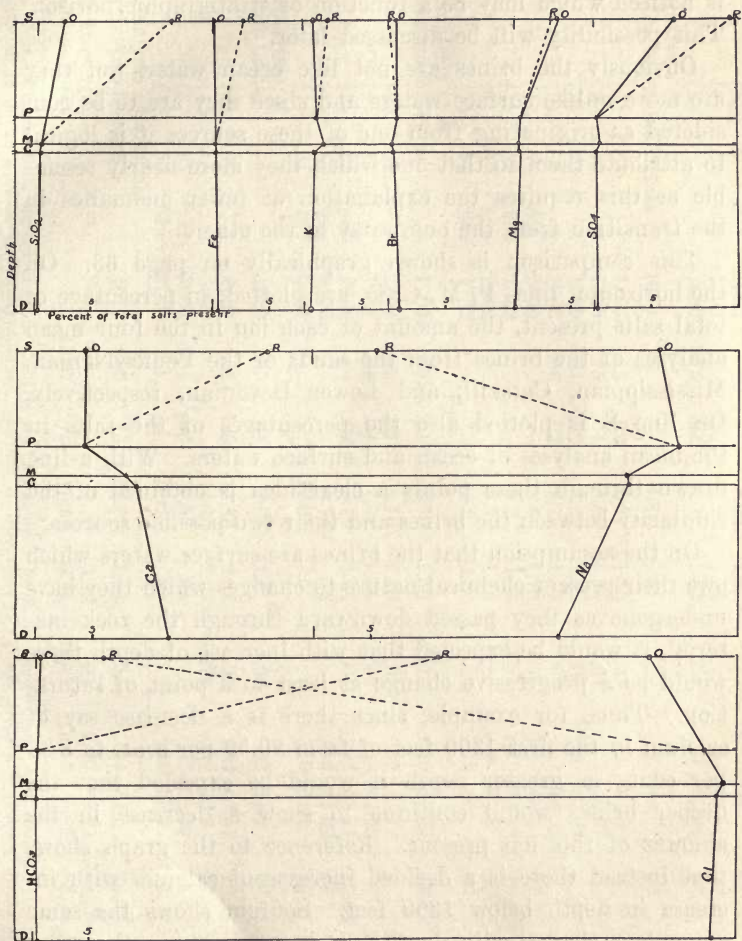
The following is a mean analysis of 8 brines collected from strata of Mississippian age expressed in parts per million parts of water:

SiO ₂	137	Na	41585
Fe	26	K	307
Ca	12740	Br	44
Mg	2295		
HCO ₃	19	Total	153000 parts of
SO ₄	1530		dissolved matter per million
Cl	95043		parts of water

The outstanding feature of the water is its high chlorine content. This makes up about the entire acidity of the water and comprises 61.12 per cent. of the total dissolved matter present. The other negative ions present, HCO₃ and SO₄, occur in small amounts, making up but about one per cent. of the salts present. Sodium is by far the most abundant of the basic ions and comprises 21.18 per cent. of the material in solution. Calcium is about one-third as abundant as sodium and consists of 8.33 per cent of the total salts present. The other basic ions occur in unimportant amounts.

In addition to their peculiar chemical nature the brines are also to be distinguished by their concentration, which is from three to seven times as great as ocean water. Another interesting feature is the similarity in content of the constituents carried by the waters. Reference to the analysis on page will show that the various salts are always present in about the same relative amounts. This is the more striking when it is considered that the waters were collected at points over an area of 10,000 square miles and from horizons of different geologic age occurring at depths of from 1000 to

¹ Reeves, Frank: *A Discussion of the Absence of Water in Certain Petroleum-bearing Strata of the Appalachian Oil Fields*. Dissertation in Johns Hopkins University Library.



Graphs showing the amount of each ion (expressed in per cent. of the total salts present) in the brines collected from Pennsylvania, Mississippi, Catskill and Lower Devonian strata and in the average Ocean (O) and river waters (R) of the world.

6000 feet. A slight change in chemical nature with depth is noticed which may be a function of stratigraphic horizon. This possibility will be discussed later.

Obviously the brines are not like ocean waters yet they are more unlike surface waters and since they are to be considered as originating from one of these sources it is logical to attribute them to that one which they more nearly resemble as this requires the explanation of fewer anomalies in the transition from the one water to the other.

This comparison is shown graphically on page 63. On the horizontal lines P, M, C, D, are plotted, in percentage of total salts present, the amount of each ion in the four mean analyses of the brines from the sands of the Pennsylvanian, Mississippian, Catskill, and Lower Devonian, respectively. On line S is plotted also the percentages of the salts in the mean analyses of ocean and surface waters. With a line drawn through these points a clear idea is obtained of the similarity between the brines and their two possible sources.

On the assumption that the brines are surface waters which owe their present chemical nature to changes which they have undergone as they passed downward through the rock material, it would be expected that with increase of depth there would be a progressive change at least to a point of saturation. Thus, for example, since there is a decrease say of calcium in the first 1300 feet of from 20.39 per cent. to 8.33 per cent., at greater depth it would be expected that the deeper brines would continue to show a decrease in the amount of this ion present. Reference to the graph shows that instead there is a decided increase of calcium with increase in depth below 1300 feet. Sodium shows the same anomalous change with depth. It is apparent, on the other hand, that, with the exception of magnesium, the ocean waters fall more in the general alignment of the graphs than do the surface waters. Of course it may be argued that the water would undergo a greater chemical change in the surface strata or in the zone of oxidation than at subsequent depths,

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Pennsylvanian

Mean Analysis of 6
Pennsylvanian brines

Reference	Page	Analysis	Depth	SiO ₂	Fe	Ca	Mg	HCO ₃	SO ₄	Cl	Na	K	Br	Salinity in percent
(1)	56	44	1200	..	..	3.45	.80	..	t	60.	33.7	.18	1.4	10.97
(1)	56	46	1200	..	..	1.1	.18	t	t	60.	37.6	t	1.6	11.09
(1)	56	47	1300	..	..	2.43	.93	..	..	61.	35.3	t	.0	10.70
(1)	57	204	1300	..	..	8.00	1.2	..	t	60.	28.	2.42	.5	12.42
(1)	57	60k	1300	..	..	7.2	1.00	..	.5	.8	30.	2.85	.8	9.42
(2)	57		1600	1.75	.01	7.1	1.53	.08	..	60.93	27.	1.50	..	10.65

Mississippi

Mean Analysis of 8
Mississippian brines

(2)	80	1	1425	.15	.02	8.77	1.33	.03	..	61.99	27.68	..	..	13.60
(2)	80	2	1355	.15	.01	8.53	1.35	.01	..	62.02	27.90	..	..	11.95
(2)	80	3	1700	.01	.02	7.29	2.02	.01	.006	62.28	28.26	..	..	14.72
(2)	80	5	2000	.06	.02	8.77	1.51	.002	..	62.17	27.44	..	..	10.56
(1)	57	60n	2000	..	..	5.6	1.73	..	1.9	60.2	30.1	.312	t	12.63
(1)	57	60c	1843	..	..	9.2	1.45	..	1.1	61.9	26.9	.29	.6	20.
(1)	57	60h	2092	..	..	9.3	1.26	..	0.9	61.3	27.3	.09	.58	20.44
(1)	57	60e	1782	..	..	9.2	1.4	..	1.13	65.	22.	..	1.6	18.47

F. Reeves

Catskill

Mean Analysis of 5
Catskill brines

(2)	81	7	2200	.02	.07	8.70	1.30	.02	.03	61.14	27.83	..	..	11.8
(2)	81	8	1623	.04	.04	7.82	1.45	.02	.08	61.96	27.24	..	..	10.11
(2)	81	10	1006	.04	.02	8.79	1.61	.04	.006	62.11	27.26	..	..	12.99
(1)	57	60g	2122	..	..	9.74	.73	..	.19	61.22	27.1	.344	.58	20.32
(1)	57	60f	2094	..	..	10.9	.9	..	.16	61.4	25.	.7	.50	17.87

Lower Dev.

Mean Analysis of 4 brines
from Lower Devonian

(3)	185	A	2667	.02	.25	13.86	2.52	.27	.03	61.3	26.86	.46	.52	14.6
(4)			5280	..	..	11.1	2.07	.0079	.03	62.31	18.35	1.53	.53	30.9
(3)	185	H	6260	..	.06	9.56	.94	..	.11	62.6	23.	.6	..	19.27
(1)	56	53p	2700	..	..	14.6	.65	..	.02	61.39	24.5	1.97	.26	26.36
				..	..			..	.39	60.9	21.	1.41	.9	27.6

Ocean water

(5)				.02	.15	12.28	1.54	.13	.14	61.2	21.71	1.4	.84	26.
(6)				11.67	2.75	1.20	3.72	.21	7.69	55.29	30.59	1.11	.188	3.5
						20.39	3.41	35.19	12.14	5.68	5.79	2.12	..	.016

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* U. S. Dept. of Agriculture, Bureau of Soils, *Bulletin* No. 94, analysis by R. F. Gardner and J. A. Challen.2 Dissection in Johns Hopkins University Library, entitled, *A Discussion of Certain non Water Bearing Strata of the Appalachian Oil-Fields*, by Frank Reeves, analysis by S. C. Dismore.3 Clark's Data of Geochemistry, *Bulletin* 616, U. S. Geol. Survey. Analysis by A. E. Robinson, C. F. Mabery, and G. Steiger.4 Introduction, *Kanawha County Report*, W. Va. Geol. Survey, page 22, analysis by Chase Palmer.5 Mean of 77 analyses of Ocean water collected from many localities by the Challenger Expedition. Cited in Clark's Data of Geochemistry, *Bulletin* 616, U. S. Geol. Survey, page 133. Analysis by W. Dittmer.6 Mean composition of river waters of the world. Cited in Clark's Geochemistry, *Bulletin* 616, U. S. Geol. Survey, page 116.

but it is hardly possible that the reactions between the waters and the rock material would produce a brine so similar to ocean water, since the alteration of river water to ocean water is effected largely by the action of organisms in the sea.

The perpendicularity of the lines uniting the brines and the ocean water indicate the similarity between the chemical nature of the present ocean and that of former seas. The variations from the straight line, with the exception of the graphs for calcium and sodium, is readily explained by the possible reactions which may have occurred between the rock material and the chemicals in solution. It will be noted, however, that there is a definite increase of calcium and decrease in sodium in passing downward from the Pennsylvanian to the Lower Devonian brines. If the waters are assumed to be of meteoric origin, then there is the anomaly of the more soluble sodium being replaced by the less soluble calcium ion as the water penetrates the earth's crust. If, however, the waters are considered to be of connate origin, then this change in depth may be a function of the geological age of the strata and hence indicate changes in the chemical content of the ocean during different geologic periods.

If the salts of the ocean have been added by the rivers, then, of course, the salinity of the ocean would increase with the age of the earth. This increase in salinity will not affect the chemical nature of the water if the relative amount of each salt remains constant. However, since organic matter and changes in physical conditions remove some salts from solution, the waters will change in nature as well as concentration. Thus the relative increase in sodium may be explained by the fact that but little of the enormous amount of this salt added continually by the rivers is lost by the ocean, while most of the other salts are constantly being removed from solution. The variation in amount of calcium in the different brines is likely due to fluctuation in the amount of CO_2 in the air during different geologic periods. This fluctuation

is a generally accepted fact ² and since there is an equilibrium between the amount of the CO_2 in the air and in the sea water it is to be expected that the sea water at times, when there is the greatest amount of CO_2 in the atmosphere, will hold a comparatively larger amount of calcium in solution as the solubility of calcium carbonate is a direct function of the amount of CO_2 present.³

The increase in concentration with depth is also an argument that the brines are indigenous to the rocks in which they occur. Richardson,⁴ however, suggests that this is due to the fact that there has been an upward diffusion of salts from the rock salt deposits that are known to underly the strata in question. But it has been pointed out that there are dry sands in the area under consideration intervening between these lower water-bearing horizons and the Mississippian sands and, as diffusion through dry strata is impossible, this suggestion seems untenable. Again, on this assumption it is difficult to understand why sodium would increase in relative amount with increase in distance from the salt beds. Reference to the analysis given will show that the Pennsylvanian brines are richer in this salt than the Lower Devonian. It appears more likely that the concentration is due to a capillary migration of the water away from the sands in which it occurs and in which it accumulated. This migration would remove part of the water and most likely leave the salt behind, because fine-grained sediments have an absorptive effect on solutions passing through them ⁵ which would result in a

² Chamberlain, T. C. "The influence of great epochs of limestone formation on the constitution of the atmosphere." *Jour. Geol.*, vol. vi, 1898, pp. 609-621.

³ Johnson, John and Williamson, E. D. "The rôle of inorganic agencies in the deposition of calcium carbonate." *Jour. Geol.*, vol. xxix, No. 8, 1916, pp. 729-750.

⁴ Richardson, G. B. "Note on the diffusion of sodium chloride in Appalachian oil field waters." *Jour. Wash. Acad. Sci.*, vol. vii, no. 3, 1917, pp. 73-75.

⁵ Turrentine, J. W. "The occurrence of potassium salts in the saline of the United States." *Bureau of Soils, Bull.* 94, 1913.

greater concentration of the waters. Considering this fact, then, the waters should show a decrease rather than an increase of mineral matter with depth, if the waters were of surface origin. Which adds more evidence to the above, that these natural brines are of connate origin.

AN UPPER CRETACEOUS SEACOAST IN MONTANA¹

By W. T. THOM, JR.

INTRODUCTION

The nonpersistence of lithologic units is the greatest obstacle to systematic stratigraphic work and correlation. Particularly is this true when it is necessary to determine the relationship of marine and continental deposits. That this difficulty may be largely overcome by a correct "paleophysiographic" perspective of the period dealt with is now becoming the accepted doctrine; and the writer has undertaken this sketch both as an illustration of the way in which ancient physiographic conditions may be deciphered and as a demonstration of the close genetic relationship of some of the different lithologic phases of the Judith River formation.

The writer studied this formation in the area lying north of the Yellowstone River, near Billings, Mont., while serving as an assistant to Eugene T. Hancock, of the United States Geological Survey, and it is with his very kind consent that this article is published. The accompanying sketch map will serve as a geographic guide to the reader in following the discussion.

STRATIGRAPHIC GEOLOGY

The later Upper Cretaceous sediments of the Montana group are exposed throughout this region, forming about 90

¹ Published by permission of the Director of the United States Geological Survey.

per cent. of the rocks outcropping within its limits. Five formational subdivisions of the Montana are present, which are, in ascending order, the Eagle sandstone, Claggett shale, Judith River formation, Bearpaw shale, and Lennep sandstone. The relationship of these units is perhaps best brought out by the accompanying diagram, but a brief description of each formation may make the details clearer.

The Eagle sandstone is developed in this area as the marine sandstone apex of a wedge of continental sediments built seaward at the close of Colorado time. The strand origin of the

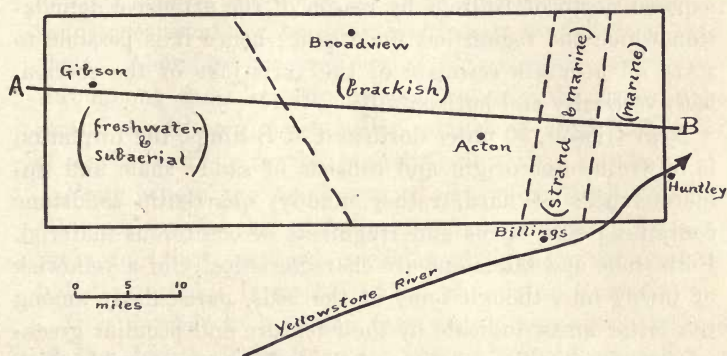


FIG. 1. Sketch map of an area in Montana.

upper part of the formation seems clearly indicated by abundant impressions of the fossil seaweed *Halymenites major*, by the coarse grain of the sandstone, and by the almost universal distribution of small, flattened chert pebbles at or near the top of the formation. The Judith River formation is much like the Eagle in mode of origin, but is thicker and shows the development of fresh-water and estuarine phases much farther east than the Eagle. The Lennep sandstone constitutes a third continental wedge, chiefly notable for the predominance of volcanic material among its component sediments. Separating these strand and coastal-plain deposits are the marine shales of the Claggett and Bearpaw formations, which thin westward and disappear at an indeterminate distance beyond the border of the area under consideration.

From this and from other evidence at hand it seems reasonably certain that the strand lines of the late Mesozoic lay nearly parallel to the present Rocky Mountain front, and that it migrated to and fro in response to the recurrent depressive movements of the period, which were gradually counterbalanced by intervening intervals of sedimentation.

DISTRIBUTION AND CHARACTER OF THE JUDITH RIVER SEDIMENTS

The sediments of the Judith River formation are now well exposed north of Billings by reason of the extensive denudation which the region has undergone; hence it is possible to form an accurate estimate of the variations of the section, both vertically and horizontally.

Near Gibson, 50 miles northwest of Billings, the formation is of freshwater origin and consists of sandy shale and numerous beds of hard, rather muddy, quartzitic sandstone containing reed stems and fragments of coniferous material. Both shale and sandstone are characteristically of a yellowish or tawny hue, though some of the beds, particularly among the softer units, indicate by their texture and peculiar greenish brown color the presence of the tuffaceous material which was thrown out so copiously by the volcanoes of the Crazy Mountains during later Upper Cretaceous and early Eocene time.

Farther east the volcanic material disappears and the section gradually assumes the aspect typical of the formation as it is developed along the Missouri and in the vicinity of Havre on Milk River; an alternation of light-gray to white clay shales with lignitic shale and carbonaceous sandstone giving the exposures a peculiar striped appearance. With the advent of the carbonaceous zones in the section the brackish water shell *Ostrea subtrigonalis* also makes its appearance at different horizons in the area immediately north of Broadview, though it is conspicuously present in but a single very thick shell bed of extraordinary uniformity and

persistence of development which lies about 50 feet above the basal sandstone of the formation.

At Acton, 15 miles northwest of Billings, the formation still retains its characteristic appearance and lithology, but east of the town a very rapid lateral variation of the sediments soon becomes apparent. The thin carbonaceous sandstones of the western section rapidly increase in magnitude and in coarseness of grain to the eastward, individual members increasing from 6 or 8 to as much as 50 feet in thickness within a distance of 5 miles. As a result the formation, as exposed about 6 miles east of Acton, consists of four massive sandstones separated by intervals of shaly sandstone or sandy shale. Abundant impressions of *Halymenites major* occur throughout these sandstones and indicate the inception of strand conditions, a conclusion confirmed by the discovery of marine fossils a few miles farther east, near Huntley.

From where the maximum of sandstone development is attained, 6 miles east of Acton, the lower sandstone members begin to taper eastward, merging into shale lithologically indistinguishable from that of the underlying Claggett.

It is further to be noted that certain surprising features of the Judith River-Bearpaw contact appear southeast of Gibson. Long, narrow ridges capped by hard andesitic sandstone are developed for considerable distances, especially near Big Lake in the so-called Lake Basin region, their general extension being from east to west or from southeast to northwest. The cap sandstones of these ridges were probably never continuous over the intervening areas, but they lie at practically an identical horizon and are so similar lithologically that they are certainly the products of the same agency.

Below these upper dark sandstones the section shows great variability; at some localities sandy beds containing more or less carbonaceous shale and lignite occupy the whole of the interval down to the more typical Judith River sediments, while elsewhere, even in the same ridge, the cap sandstone may overlies typical Bearpaw shale with only a

few feet of thin-bedded white sandstone intervening. From this and from other corroborative evidence the conclusion therefore seems natural that the ridges represent the radiating channel sandstones of an ancient delta, which was built out into the marine waters of the incipient Bearpaw sea by a river of considerable size flowing from the south or south-west.

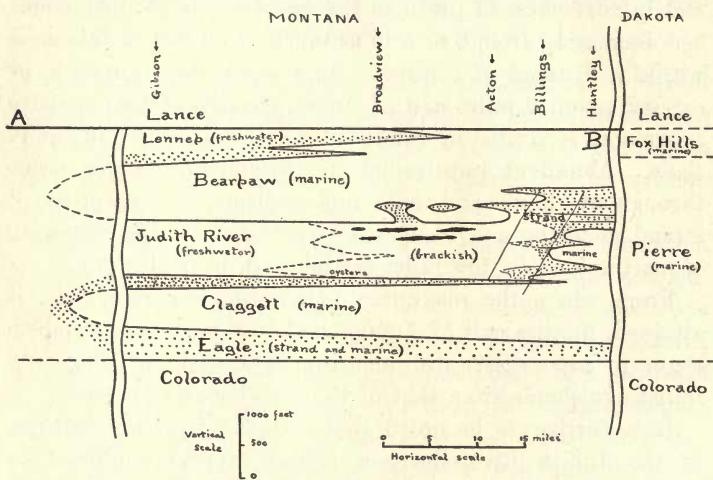


FIG. 2. Section showing the relation of the sediments.

PALEOGEOGRAPHIC INTERPRETATION

Upon the basis of the foregoing data the writer draws the following picture of the physiography of Judith River time.

The low coastal plain of the mainland lay to the east of the Crazy Mountains, very possibly extending thence a little beyond Gibson, and upon it a gradually increasing thickness of freshwater and subaerial deposits was laid down as regional subsidence progressed. Simultaneously a sandy barrier beach was developed and maintained in the area east of Acton, thus partially shutting off a shallow embayment or lagoon whose quiet waters, rendered brackish by the regional drainage,

afforded a favorable habitat for multitudes of oysters, which were later buried by the burden of fine silt accumulating in the quiet waters of the bay. Still later, as sedimentation gained upon subsidence, the site of the one-time oyster bed became the location of repeated coastal swamps, in which were formed the lignitic beds and carbonaceous zones now so conspicuous in the upper part of the formation.

Subsequent revival of the local depressive movements of the crust temporarily restored the old embayment, into the southern end of which a large river built out a delta, even as the marine shales of the Bearpaw were being laid down in the deeper part of the bay a little farther north. As a final phase more rapid depression carried marine waters farther westward, and the Bearpaw sea covered the whole area.

A REMARKABLE UPPER CRETACEOUS FAUNA FROM TENNESSEE¹

By BRUCE WADE

During the summer of 1915 the Tennessee Geological Survey located well-preserved fossils in the Ripley formation in the northeastern part of McNairy County, Tennessee. An incomplete collection was made from the locality in this region where the strata containing the fossils are best exposed. This collection was studied during the winter in the Geological Laboratory of the Johns Hopkins University. This partial study of the fauna has resulted in the differentiation of nearly 300 species, and investigations show that no single locality yet reported from the Cretaceous of North America has furnished such a large fauna made up of such well-preserved shells.

The Gastropods are unusually abundant and include not only

¹ Published with the permission of Dr. A. H. Purdue, State Geologist of Tennessee.

a large number of new species but several forms which are regarded as new genera.² Further collections were made at this place and in the adjoining regions during the field-season of 1916. The writer has begun, for the Tennessee Geological Survey, an investigation of all the Upper Cretaceous deposits of the state and hopes to submit in the near future a detailed report on the Stratigraphy and Systematic Paleontology of these rocks.

GENERAL GEOLOGICAL RELATIONS.

The Upper Cretaceous deposits of Tennessee outcrop in a wedge-shaped area which crosses the State in a nearly north and south direction, and lies largely west of the Tennessee River in the west-central part of the State. This area is about 67 miles wide along the southern boundary of the State, narrowing to the northward until at the Kentucky line it is only about 15 miles in width.³ Along the southern border of the State in Wayne, Hardin, McNairy and Harde-man counties these deposits may be segregated into the following lithologic units.

Ripley formation	{ Owl Creek horizon McNairy sand member Ferruginous clay horizon Coon Creek horizon
Selma chalk	
Eutaw formation	
Tuscaloosa formation	

The present discussion is limited to the lower part of the Ripley. This formation covers the western two-thirds of McNairy County, and in general is well exposed over that entire region. The four horizons or members of the Ripley

² Some of these have been described in the *Proc. Phila. Acad. Nat. Sci.*, 1916, pp. 455-471, pl. 23, 24.

³ Jenkins, O. P., Geological Map of Tennessee, State Geol. Survey, 1915.

named above may be traced across the county by their contained faunas and lithology, even though there are no sharp lines of demarcation separating the one from the other. The sediments of the Coon Creek horizon, which are described in detail below, are quite variable, ranging from local lenses of impure limestone through very fossiliferous marls to glauconitic sands and gypsiferous clays poor in fossils. The overlying ferruginous clay horizon is sparsely fossiliferous and extends across the county in a belt about three miles wide. The McNairy sand member next above, which is typically exposed in McNairy county, has been described by Stephenson.⁴ This member is essentially a sand and has yielded few fossils. The so-called fucoid *Halymenites major* Lesq. occurs sparingly. In 1915 leaves were collected from near Selmer, Tenn., and Big Cut, Tenn., the type section for this number. These have been submitted to Prof. E. W. Berry for study. Above the McNairy sand and exposed along southwestern McNairy County and southeastern Hardin County is a fossiliferous horizon which may be traced southward into Mississippi to Owl Creek, the type locality for the Ripley formation.

COON CREEK LOCALITY AND ITS STRATIGRAPHIC POSITION.

The locality under immediate discussion may be known as the Dave Weeks place on Coon Creek. It is in the northeastern part of McNairy County, 3½ miles south of Enville and 7½ miles north of Adamsville and ⅓ mile east of the main Henderson-Adamsville Road. The beds containing the fossils are best exposed in the valley about two hundred and fifty yards east of Dave Weeks' house along the headwaters of Coon Creek. This is a small stream flowing northward into White Oak Creek, a tributary of the Tennessee River.

Upper Cretaceous fossils have been previously collected

⁴ Stephenson, L. W., U. S. Geological Survey, 1914, Prof. Paper 81, p. 22.

from a few places in this general region of the Mississippi radius of $7\frac{1}{2}$ miles of the Dave Weeks' place. At a point $\frac{1}{4}$ mile west of Adamsville Stephenson⁵ made a collection from the *Exogyra ponderosa* zone of the Selma chalk. Four miles northeast of Adamsville he made another collection from the same zone at a locality referred to as "four miles southwest of Coffee Landing." Three miles west of Adamsville fossils were found by Stephenson in the *Exogyra costata* zone of the Selma chalk. About eleven miles southwest of the Coon Creek locality and "two and one-half miles east of Purdy," Safford⁶ collected in the uppermost part of the formation which he designated as the "Green Sand." The horizon from which this last collection was made probably has the same stratigraphic position as the Coon Creek beds. The best-known fossil locality in this general region is the classic Owl Creek locality⁷ in Tippah County, Mississippi, often referred to in the literature as Ripley, Mississippi. (See sketch map, Fig. 1.)

A sketch map has been inserted on page 77 to show the location of Coon Creek and Owl Creek and to give in a general way the areal geology in the region about these localities. Big Cut and Coffee Landing, two other important localities in the Cretaceous Geology of Tennessee are shown on this map. The information given on the map south of the Tennessee-Mississippi line has been furnished by Dr. L. W. Stephenson of the United States Geological Survey.

The Coon Creek horizon is stratigraphically near the base of the Ripley formation and in the *Exogyra costata* zone.

⁵ *Idem.*, p. 24.

⁶ Safford, J. M., *Geology of Tennessee*, 1869, p. 416.

⁷ Conrad, T. A., *Jour. Acad. Nat. Sci.*, Philadelphia, 1858, vol. iii, 2d ser., pp. 323-336.

Conrad, T. A., *Jour. Acad. Nat. Sci.*, Philadelphia, 1860, vol. iv, 2d ser., pp. 275-298.

Stephenson, L. W., U. S. Geological Survey, 1914, Prof. Paper 81, p. 24, table 2.

The Selma-Ripley contact is well established at Blue Cut on the Mobile and Ohio Railroad at the state line on the southern extremity of McNairy County. From this point the con-

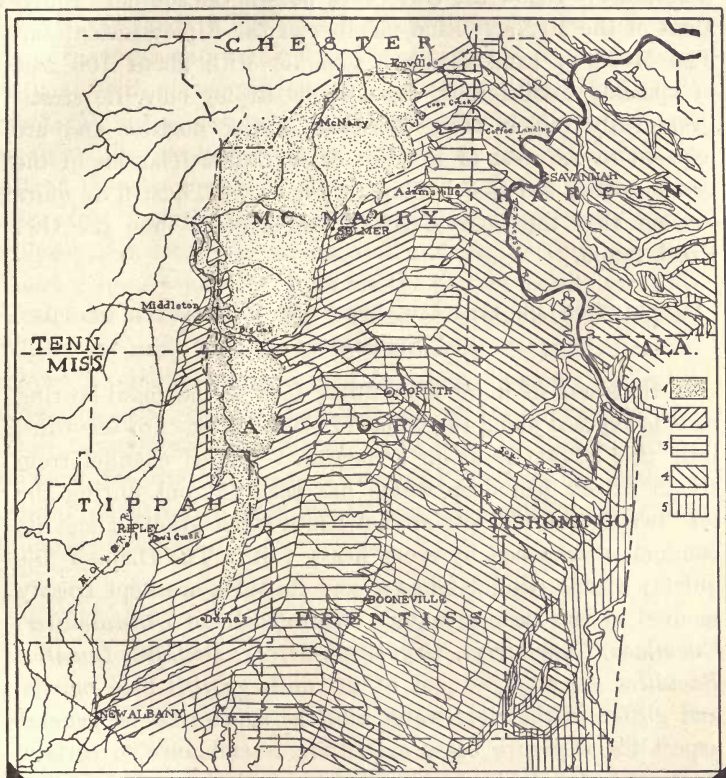


FIG. 1. Map showing the areal geology of a portion of Tennessee and Mississippi.

- 1, McNairy Sand Member; 2, Ripley Formation; 3, Selma Chalk; 4, Eutaw; 5, Tuscaloosa.

tact may be readily traced both by lithological and faunal relations to Coon Creek. It is thus evident that the Coon Creek horizon lies just above the Selma chalk and at the base of the Ripley. The Coon Creek horizon is thus strati-

graphically lower than that along Owl Creek in Mississippi. At the latter locality the fossiliferous horizon is in the uppermost beds of the Ripley and is directly overlain by Eocene limestone.⁸ Below the Owl Creek beds is the southern equivalent of the McNairy sand member of the Ripley formation.⁹ The McNairy sand member, together with about 100 feet of sparsely fossiliferous, ferruginous Ripley clay, lie stratigraphically higher than the Coon Creek horizon and are exposed to the west of it. (For cartographic relations of the two localities see sketch map in Fig. 1.) Thus, it is quite evident that the Coon Creek fauna is older than the Owl Creek fauna.

DESCRIPTION OF THE LOCALITY AND CHARACTER OF THE SEDIMENT

A thickness of more than thirty feet of the fossil-bearing beds is exposed along the banks of Coon Creek. For one-third mile this stream flows in a narrow V-shaped channel from six to fifteen feet deep which has been cut out during the last twenty years. The stream has a steep gradient and its channel is deepened by every heavy rain. The channel fills quickly after a thundershower and its sides are kept freshly scoured by the rushing water. White shells of *Crassatellites*, *Cucullaea*, *Cyprimeria*, *Gryphaea*, *Ostrea*, *Drilluta*, *Lunatia*, *Baculites*, etc., project out of the dark greyish blue matrix and glitter in the clear water and the sunshine. In general aspect the exposure bears a striking resemblance to certain Tertiary beds. In broad physiographic relations, character of the matrix and whiteness of the shells, the Coon Creek locality resembles the well-known Upper Cretaceous exposure of Brightseat, Maryland. This locality is two miles east of District Line and has yielded the most prolific Upper Cretaceous

⁸ Harris, G. D., The Midway Stage, *Bull. Amer. Pal.*, vol. 4, no. 4, 1896, p. 24.

⁹ Stephenson, L. W., Paper given before the Paleontological Society of America, December 29, 1916.

Lowe, E. N., Geology of Mississippi, *Bull.* 12, 1915, p. 62.

fauna of Maryland. The shells, notably the bivalves, are probably more abundant at Brightseat, but not so well preserved as they are at the Tennessee locality. The sediments containing the Coon Creek fauna are dark bluish green and gray clayey sands. The sand is of medium fineness and consists of angular and rounded grains of quartz as the major constituent, with glauconite, small flakes of mica, and shell fragments as minor constituents. Pieces of lignitic wood and small nodular masses of pyrite are common but not abundant. All of the above clastics are cemented together with a fine calcareous material, forming a compact impervious mass which varies locally in arenaceous and argillaceous content. There is locally sufficient lime for the matrix to become indurated into a very hard, impure and concretionary limestone. When this marl is thoroughly weathered the shells are removed leaving casts in a matrix which becomes yellowish brown in color, due to the oxidation of the glauconite and other ferruginous constituents. Dr. Paul C. Bowers, Chief Chemist for the Tennessee Geological Survey, has made a careful quantitative analysis of this marl and reports the following results:

SiO ₂	65.30
Al ₂ O ₃	8.56
Fe ₂ O ₃	3.72
FeO	1.72
MnO	.44
CaO	7.10
MgO-	.70
Na ₂ O } K ₂ O }	2.42
P ₂ O ₅	trace
FeS ₂	.45
CO ₂	5.15
H ₂ O	5.45
Carbon	.09
Total	101.00

HISTORICAL SKETCH

The well-preserved fossils of the Ripley formation attracted the attention of the early geologists and impressed them very much. In 1856 Conrad ¹¹ described fifty-six new species from Owl Creek and made the following observations about the fauna:

“The Cretaceous strata of Mississippi have long been observed and partially noted by geologists and the lamented Professor Tuomey has described a number of their fossil contents. I now introduce quite a distinct group of shells, which are imbedded in a different matrix compared with the prevalent cretaceous marls, green sands and limestones. The discovery of these beautiful organic remains is due to the indefatigable exertions of Dr. W. Spillman, of Columbus, who has forwarded a collection of specimens more or less perfect, consisting of nearly sixty species, all of which appear to be unpublished except *Scaphites conradi*. The appearance of these shells is like that of eocene species which have merely lost their animal matter, and in this respect are very unlike the condition of similar genera in the contiguous rocks of the same era. The fossils are imbedded in a sandy marl of a dark gray color, the principal constituents of which are fine scales of mica and grains of quartz mixed with fragments of small shells; and though some of the very thin species are distorted, the stronger retain their original shapes and are generally very perfect. Species of *Crassatella*, *Nucula* and *Meretrix* have the valves united as in life, as well as a few of the extremely thin *Inocerami*, though the latter are more or less distorted by pressure. The numerical proportion of species of Cephalo and Acephalo is nearly equal. The external sculpture of all is as sharply defined as in existing species. Besides *Scaphites* and *Baculites*, there is only one shell in the collection which resembles a species of the green sand or lime-

¹¹ Conrad, T. A., *Jour. Acad. Nat. Sci.*, Philadelphia, 2d ser., vol. iii, pp. 323-336.

stone, and it is quite distinct. The rare genus *Pulvinites* is herein for the first time introduced as an American form. The analogous species, as well as that of *Gervillia*, occur in the Baculite limestone of France and Normandy, which I believe is referred by d'Orbigny to his Senonian Stage, the same in which he included the Cretaceous fossils of North America.

"It is interesting to find bivalves of so remote an era in sufficient preservation to exhibit generic characters as clearly defined as they are in living shells. In this condition are the hinges of *Gervillia*, *Pulvinites*, *Otenoides* and *Cardium*. Here are also specimens of *Baculites* and *Scaphites* which exhibit the interior divested of all extraneous matter, and delight the eye with exquisite curves of the foliated septa, whilst the shells glow with brilliant iridescent tints.

"This beautiful series of Cretaceous forms seems to be very limited in geographical distribution, so far as our present knowledge extends. It is probably unknown as yet beyond the limits of Tippah County, which borders on Tennessee. No account has been given of such a group by the State Geologists of Tennessee or Alabama. Dr. Spillman informs me, 'The fossils you have now under examination were found in the bluffs of Owl Creek, three miles north of the town of Ripley,' and he concurs in opinion with me that they might properly be named the 'Ripley group.' He also remarks that *Ammonites placenta* occurs in it with the shell preserved, and that in connection with the Ripley group, or in the same locality, are '*Exogyra costata*, *Gryphaea mutabilis*, *Ostrea plumosa*, *Natica petrosa*, *Nautilus DeKayi*, etc., with the shells more or less preserved, in an argillo-calcareous marl,' but none of these species are contained in his collections sent me from Tippah County."—Conrad, 1858.

After this announcement of the discovery of well preserved Cretaceous fossils in northern Mississippi was made by Conrad, Safford collected a few Ripley fossils from near Purdy, Tennessee and Tuomey made a large collection of unusually well preserved shells at Eufaula, Alabama, from the same

horizon as Owl Creek. These collections were sent to Conrad and Gabb for study and their contributions appeared in 1860 in Volume IV of the *Journal of the Philadelphia Academy of Natural Sciences*. In this volume Conrad described fifty-four additional new species and Gabb four new species collected from northern Mississippi, Alabama and Tennessee. Since the work of these men, very little has been done on this unusually prolific fauna. Geologists have often visited Owl Creek and collections have been made but nothing has been published on the systematic paleontology except for minor contributions.¹² The most recent check list of the Ripley collections in the National Museum from this region is that published by Stephenson in 1914.¹³

STATE OF PRESERVATION OF FOSSILS

A comparison of specimens from the Coon Creek collection with forms from Owl Creek in the National Museum shows that the shells from the former locality include many small and fragile individuals, and that many individuals present delicate shell parts, internal and external markings not so well defined, or entirely absent in the Tippah County Specimens. The hinge areas, muscle scars, buttresses, pallial lines and external sculpture are as sharp and as well defined in such genera as *Cucullaea*, *Glycymeris*, *Crassatellites*, *Nucula*, *Cardium*, *Trigonia*, *Paranomia*, etc., as in the shells of Tertiary and Recent bivalves. Even the ligaments are occasionally preserved and in their natural positions in attached valves of *Cardium* n. sp. *Cyprimeria* n. sp. and *Leptosolen biplicata* Conrad. Many of the Gastropoda, including species of such genera as *Liopeplum*, *Gyrodontes*, *Ptychosca*, *Volutomorpha*, *Pugnellus*, etc., are brilliantly glazed. The shells of *Eutrophoceras*, *Baculites*, *Scaphites*, and *Turrilites* are well

¹² Dall, 1890, *Trans. Wagner Free Inst. Sci.*, Philadelphia, vol. iii, pt. 1, p. 73.

Dall, 1907, *Smiths. Misc. Coll.*, vol. iv, pt. 1, pp. 1-23.

¹³ Stephenson, L. W., *loc. cit.*, p. 24, tables 1-9, 1914.

preserved and abundant but in many cases have been crushed by the weight of the superincumbent sediments. The protoconchs are well defined and in a perfect state of preservation on many of the Gastropoda, especially such genera as *Laxispira*, *Volutoderma*, *Paladmete*, *Thylacus* and many others. The protoconch is present and sharply differentiated in a new species of *Teinostoma* which is strikingly like the Miocene form *Teinostoma nana* (Lea). The adult itself is only a little more than 1 mm. in its greatest dimension, yet the shell and protoconch are both brilliantly glazed and look as fresh as if they were Recent. The small and fragile Scaphopod *Cadulus obnatus* (Conrad) is abundant and perfectly preserved. Such over-specialized and projecting shell parts as the anterior calcareous tube and the fringing tubules of the genus *Clavagella*, and the spinose and flaring outer lips of such genera as *Anchura*, *Aporrhais*, *Volutoderma*, etc., occur unbroken. Fragments of non-lignitized and non-petrified wood are common and resemble Recent wood in state of preservation as shown by weight, color and woody fiber.

The occurrence of so many perfect shells in unconsolidated sediments as old as the Cretaceous is exceedingly rare. Although these fossils have retained their original characters and shell material many of them are soft and fragile so that some care is necessary in collecting and preparing them. They are easily removed from the strata with part of the matrix attached. This serves to protect the specimens in packing and shipping. When the collected material dries the sandy matrix may be readily cleared away, leaving most of the shells hard and fairly strong. The weaker specimens can be made harder and sufficiently strengthened to withstand handling and the effects of the atmosphere by a method of preparing which is used here in the Geological Laboratory. After all foreign matter has been removed from the shells they are soaked about four minutes in paraffin heated to the boiling point. The hot wax permeates the shell walls and reinforces them. The shells are darkened slightly by the wax but otherwise the method is altogether satisfactory.

At both the Owl Creek (Miss.) and Brightseat (Md.) localities the fossil beds occur directly below the Cretaceous-Eocene contact. This contact represents a long interval of erosion during which the shell beds were at, or very near, the surface and were probably subjected to the action of circulating meteoric waters which had a disintegrating effect on the shells. The abundant springs at this horizon show that during late Pleistocene and Recent times this unconformable Cretaceous-Eocene contact has furnished an easy channel for ground waters which have attacked the unpetrified shells. At Coon Creek, on the other hand, the conditions are somewhat different. There is no overlying unconformable contact directly above the fossil beds but instead there is a great thickness of overlying impervious Ripley clays. The shells were sealed up by the Upper Cretaceous sea in compact, calcareous sandy sediments and have been, it seems unaffected by circulating ground waters until the dawn of the present physiographic conditions. Even now these beds are so impervious that the ground water does not penetrate them, as is shown by the fact that well-drillers have reported the strata perfectly dry. The character of the matrix at the three localities is essentially the same, so that it seems reasonable to assume that the Coon Creek shells are well preserved because they have been protected from circulating ground waters the action of which is so evident in most Cretaceous strata.

OBSERVATIONS ON THE FAUNA

The Coon Creek fauna is both prolific and varied. Four days collecting at this locality yielded, according to preliminary determinations a fauna of 134 genera and 269 species, and further collecting has materially increased this number. The study is yet incomplete and some of the determinations are merely tentative but the following generalizations may be made. In the 134 genera already recognized there are, exclusive of the Mollusca, three genera of Vertebrata of the Class Pisces; 5 of Arthropoda of the Class Eucrustacea; 9 genera

of Molluscoidea of the Class Bryozoa; 1 genus of Echinodermata of the Class Echinoidea; 2 of Vermes; and 1 of Coelenterata of the Class Anthozoa. The Mollusca, however, are by far the most abundant. In this group there are 49 genera and 110 species of Pelecypoda; 2 genera and 3 species of Scaphapoda; 60 genera and 120 species of Gastropoda; 4 genera and 7 species of Cephalopoda.

It has been estimated that the Recent east coast Molluscan fauna of the Middle Atlantic States includes more than 500 species, and there is no reason to suppose that the Upper Cretaceous faunas were materially less prolific. On the contrary, the seas were warmer and conditions more favorable to molluscan life, so that probably not more than one-half the entire fauna has been discovered.

The Coon Creek fauna flourished near the head of the Mississippi Embayment and in about the same latitude as the Middle Atlantic States. It was probably in the same general climatic zone of the Cretaceous, so that any estimate of the east coast fauna should hold for the northern part of the Mississippi Embayment as well. The evidence afforded by the Coon Creek material shows that the above estimate is not overdrawn but probably conservative. The extent of the undescribed fauna is indicated by the fact that four days collecting at Coon Creek has yielded in the Mollusca alone over 100 new species, three new subgenera and eight new genera.

The families and genera with the number of species in each are as follows (a preliminary list made May, 1916):

CLASS PELECYPODA

Order Prionodesmacea

Naculidae.	Nucula.....	3 species
Ledidae.	Leda.....	2 species
	Yoldia.....	1 species
Parallelodontidae.	Nemodon.....	3 species
	Cucullaea.....	4 species
Arcidae.	Arca.....	4 species
	Glycymeris.....	2 species
	Axinea.....	1 species
	Postligata.....	1 species

Perniidae.	Inoceramus	3	species
	Gervillioopsis	1	species
Pteriidae.	Pteria	2	species
Ostreidae.	Ostrea	8	species
	Exogyra	1	species
	Pycnodonte	1	species
	Gryphaeostrea	1	species
Trigoniidae.	Trigonia	2	species
Pectinidae.	Pecten	4	species
Limidae.	Lima	2	species
Anomiidae.	Paranomia	3	species
	Anomia	3	species
	Pulvinites	1	species
Mytilidae.	Modiolus	1	species
	Lithophaga	3	species
	Crenella	2	species
Dreissenidae.	Dreissena	1	species

Order Anomalodesmacea

Anatinidae.	Periplomya	1	species
	Anatimya	1	species
	Corimya	1	species
Clavagellidae.	Clavagella	2	species
Poromyacidae.	Liopistha	3	species

Order Teleodesmacea

Pleurophoridae.	Veniella	1	species
Crassatellitidae.	Crassatellites	4	species
Astartidae.	Vetericardia	1	species
Diplodontidae.	Tenea	3	species
Cardiidae.	Cardium	4	species
Veneridae.	Cyclina	2	species
	Meretrix	4	species
	Legumen	2	species
	Cyprimeria	1	species
Tellinidae.	Linearia	2	species
Solenidae.	Leptosolen	1	species
Mactridae.	Spisula	1	species
Corbulidae.	Corbula	4	species
Saxicavidae.	Panope	2	species
Pholadidae.	Pholidea	2	species
Teredinidae.	Teredo	4	species. ¹⁴

CLASS SCAPHOPODA

Dentaliidae.	Dentalium	2	species
Siphonodentaliidae.	Cadulus	1	species

¹⁴ Besides the above named genera there are probably two others in the collection whose generic relations have not been determined on account of fragmentary material.

CLASS GASTROPODA

Order Opisthobranchiata

Suborder Tectibranchiata

Acteonidae.	Acteon	.....	5 species
	Tornatella	.....	2 species
Ringiculidae.	Ringicula	.....	1 species
Scaphandridae.	Cylichna	.....	1 species.

Order Ctenobranchiata

Suborder Toxoglossa

Cancellariidae.	Paladmete	.....	3 species
	Matata	.....	1 species
Turritidae.	Turris	.....	1 species
	Surcula	.....	6 species
Volutidae.	Volutoderma	.....	3 species
	Volutomorpha	.....	5 species
	Tectaplica	.....	1 species
	Liopeplum	.....	1 species
	Drilluta	.....	2 species
	Ptychosyca	.....	2 species
Mitridae.	Mitra	.....	1 species
Vasidae.	Xancus	.....	3 species
Fusidae.	Fusus	.....	2 species
	Subgenus Anomalofusus	.....	1 species
	Ornopsis	.....	2 species
Fasciolaridae.	Piestochilus	.....	1 species
	Odontofusus	.....	3 species
Thaisidae.	Sargana	.....	2 species
Busyconidae.	Busycon	.....	1 species
	Pyropsis	.....	3 species
	Pyrifusus	.....	3 species
Buccinidae.	Hemifusus	.....	1 species
	Hydrotribulus	.....	2 species
Nyctilochidae.	Tritonium	.....	1 species
Columbellariidae.	Columbellina	.....	1 species
Strombidae.	Pugnellus	.....	1 species
	Rimella	.....	1 species
Aporrhaidae.	Aporrhais	.....	6 species
	Anchura	.....	2 species

Suborder Streptodonta

Scalidae.	Pseudomelania	.....	1 species
Vermetidae.	Laxispira	.....	1 species
Turritellidae.	Turritella	.....	8 species
Naticidae.	Gyrodes	.....	3 species
	Lunatia	.....	2 species
Capulidae.	Thylacus	.....	1 species
Littorinidae.	Littorina	.....	1 species

Order Aspidobranchiata

Eulimidae. <i>Leiostraca</i>	1 species
Euomphalidae. <i>Hippocampoides</i>	1 species
Turbinidae. <i>Schizobasis</i>	1 species
Trochidae. <i>Solariella</i>	2 species
Umboniidae. <i>Teinostoma</i>	1 species
Delphinulidae. <i>Urceoabrum</i>	1 species
Liotali	3 species. ¹⁵

CLASS CEPHALOPODA

Order Nautiloidea

Nautilidae. <i>Eutrophoceras</i>	1 species
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Order Ammonoidea

Lytoceratidae. <i>Baculites</i>	3 species
Turrilites	1 species
Cosmoceratidae. Genus <i>Scaphites</i>	1 species

Probably the most significant fact revealed by the above list is that the number of univalve species is greater than the number of bivalve species. However, all three orders of the Pelecypoda are well represented. Of the Order Prionodesmacea the three families represented by the greatest number of forms are the Arcidae, Ostreidae and Mytilidae. The last two had their beginning in the Paleozoic. The Arcidae originated and suddenly became a prominent group in the latter part of the Mesozoic and developed into very great importance in the Tertiary. Each of these three families is represented by four genera at Coon Creek. Among the Anomalodesmacea there are three families and five genera. The Teleodesmacea are well represented. Of this order probably the individuals of the families Cardiidæ, Veneridæ, and Corbulidæ are most abundant. A comparison of the above list with lists from the East Coast Cretaceous shows that the bivalves are relatively less abundant in the Coon Creek horizon than in corresponding horizons in New Jersey and the Middle Atlantic States. Several genera such as *Cuspidaria*,

¹⁵ Besides the above named genera there are probably thirteen genera and more than that number of species whose generic relations have not been determined on account of the fragmentary condition of the material.

Myrtaea, *Phacoides*, *Docinia*, *Tellina*, *Solyma*, etc., are absent from the present McNairy County collection though it is probable that further collecting may reveal some of them.

The Scaphopoda are represented by the two families Dentaliidae and Siphonodentaliidae. The former originated in the Ordovician and are abundantly developed in the Cretaceous and Tertiary. They are represented at Coon Creek by one genus and two species, one of which is very common. The family Siphonodentaliidae is first found in the Cretaceous. At Coon Creek it is abundantly represented by the minute form *Cadulus obnutus* (Conrad).

The Gastropoda are the most interesting class in the Coon Creek fauna. It will be noted from the list given above that the number of genera and species of the Gastropoda is considerably greater than the number of the Pelecypoda, yet, probably in every cubic yard of the Coon Creek sediments the number of bivalve individuals exceeds the univalve individuals several times. In all the faunas previously reported from the Cretaceous of Eastern United States the bivalve species are more numerous than the univalve species. This majority among the latter may be due simply to the fact that in the Upper Cretaceous seas of those regions the pelecypods predominated in number of species as well as individuals, or it may be that a greater number of gastropod species existed in all the Cretaceous seas but were not preserved sufficiently to be recovered from the sediments. The chance of preservation of gastropod shells is not as good as it is for pelecypods, first, because the number of individuals per species of the Gastropoda is rarely ever as great as it is among the Pelecypoda. Second, the essential constituent of univalve shells is aragonite, and this mineral is much less stable than calcite, which is the essential constituent of the majority of pelecypod forms. Third, a gastropod shell is in greater danger of being crushed by the pressure of the inclosing sediments because of lack of support from within the shell. The body cavity of gaping bivalved shells is almost of necessity filled, while the sediments are intruded less readily

through the aperture in the spiral body cavities of univalves. The shells thus unsupported within become crushed by superincumbent sediments and are then rapidly disintegrated.

In general, the Tertiary and Recent faunas of North America contain a greater number of univalves species and it may be that about the same proportion existed in all the Cretaceous faunas. Yet it may be that the faunas, as they have been reported, represent the natural proportions in which these animals lived in the Cretaceous sea. It is possible that the gastropods became diversified in the Cretaceous and that this diversification took place only in certain provinces, where environments favored variation. Excavating and extensive collecting in localities where the shells are especially well preserved will probably throw some light on this question.

In the order Opisthobranchiata there are three families and four genera found in the Coon Creek collection. Of these the family Acteonidae, which had its beginning in the Devonian and gained great prominence in the Mesozoic is represented by the genera *Acteon* and *Tornatella*. The former includes probably five species and the latter two. The families Ringiculidae and Scaphandridae are each represented by one genus and one species.

The order Ctenobranchiata is most abundant and is represented by 48 genera, 30 of which belong to the suborder Toxoglossa and 18 to the suborder Streptodonta. Among the Toxoglossa the family Cancellariidae is first differentiated in the Upper Cretaceous. It appears suddenly much diversified in that period and attains its maximum distribution in the late Tertiary and Recent. This family is represented at Coon Creek by two genera. The most prolific of these is *Paladmete*, a genus first recognized and described by Dr. Julia A. Gardner who has recently monographed the Upper Cretaceous Mollusca of Maryland.¹⁶ The type species of *Paladmete* is very abundant in Maryland and north-

¹⁶ Gardner, J. A., Md. Geol. Survey, Upper Cretaceous vol., Text, p. 412, 1916.

ern Mississippi. The genus is represented by three species at Coon Creek. *Mataxa* is a form regarded by me as a new genus and is referred to the Cancellariidae. A species of *Mataxa* has been described from South India by Stoliczka¹⁷ and assigned to the genus *Narona* of the Cancellariidae. A study of Stoliczka's description and figures together with perfect specimens from Coon Creek shows that these species belong to the same genus which is evidently not *Narona*, so it seems advisable to assign these two forms to *Mataxa* as a new genus in the Cancellariidae. The Turritidae is another family which is represented in the Cretaceous by several forms and is not found in earlier strata. There are two genera of this family at Coon Creek, *Turris*, and *Surcula*. The latter is especially varied, and includes probably six species.

The Volutidae is the most prolific and interesting family of the Coon Creek collection. It contains six genera and sixteen species, nearly all of which are represented by abundant, well characterized and perfectly preserved shells. The remarkable efflorescence of the Volutes in the Upper Cretaceous has been discussed by Dall who monographed the Volutidae in 1890¹⁸ and in 1907.¹⁹ The Coon Creek Volutes include the genera *Volutomorpha*, *Volutoderma*, *Ptychosyca*, *Liopeplum*, two new genera, *Drilluta* and *Tectaplica* and two species of a form whose generic relations have not been fully determined. The genus *Ptychosyca* was named and described by Gabb in 1876.²⁰ Dall did not consider this genus a Volute in his monograph of this family, but two species represented by well preserved material in the McNairy County collection reveal new characters that indicate that this form

¹⁷ Stoliczka, F., Geol. Surv. of India, *Cret. Faunas of South India*, vol. ii, p. 166, pl. xiii, figs. 15, 16.

¹⁸ Dall, 1890, *Trans. Wagner Free Inst. Sci.*, Philadelphia, vol. iii, pt. 1, p. 72.

¹⁹ Dall, 1907, *Smiths. Misc. Coll.*, vol. iv, pt. 1, pp. 1-23.

²⁰ Gabb, W. M., *Proc. Acad. Nat. Sci.*, Philadelphia, 1876, p. 295, pl. 17, figs. 2-4.

is quite probably a member of the Volutidae and near the genus *Liopeplum*.

The Mitridae and Vasidae are each represented by one genus. The genus *Xancus* of the Vasidae is represented by three species which are well characterized by the manner of excavation of inner lip and number of columellar folds. This genus is well represented in the Upper Cretaceous and was first identified from the Cretaceous quite recently by Dr. Gardner.²¹ The Fusidae which appeared in the Jurassic and are widely developed in the Tertiary and Recent are represented at Coon Creek, besides the genus *Fusus*, by a form which is considered of the rank of a subgenus under *Fusus* and given the name *Anomalofusus* as a new subgenus. The Fusidae are further represented by two very common well characterized species for which the new genus *Ornopsis* has been proposed. The family Fascioliariidae embraces the genera *Piestochilus* and *Odontofusus*, the latter being represented by three species which are very closely related. The well-characterized genus *Sargana*, of the Thaisidae, is represented at Coon Creek by two species, one of which is very abundant and perfectly preserved.

The family Busyconidae is interesting in that it appears rather suddenly in the Cretaceous with numerous, diversified representatives. At Coon Creek it is represented by three genera and seven species. These genera are *Busycon*, *Pyropsis* and *Pyrifusus*.

Pyropsis and *Pyrifusus* are very abundant in the Cretaceous and have a world-wide distribution. *Busycon*, very commonly known as *Fulgur*, is rarely found in the strict sense in the Cretaceous. This extension of the range of this common East Coast Tertiary and Recent form is of particular interest. It is represented in the present Coon Creek collection by a single well preserved specimen, a description of which has been prepared for publication. This specimen, aside from the absence of the protoconch is perfect and pre-

²¹ Gardner, J. A., *loc. cit.*, p. 434.

sents generic characters which cannot be mistaken. The species bears a striking resemblance to some of the medium-sized late Tertiary and Recent species. All the typical *Fulgurs* previously known have been limited to the Tertiary and Recent of the Atlantic States. The Eocene forms are small, rather thin-shelled species, so it has been considered that the genus evolved during that period. The living *Fulgurs* have been very extensively studied and the life history carefully worked out. The limited geographic range has been explained in a large measure by the fact that the animal is deprived of an active free-swimming larval stage by the loss of the velum before the young form emerges from the egg-capsule. This same fact might well be cited to explain the very limited distribution of *Busycon* in the Cretaceous. One of the earliest Tertiary species (described and referred to genus *Fulgur* by Harris²²), occurs in the Midway group of the Eocene about 30 miles west of Coon Creek.

In the family Buccinidae there is a species represented by large elegant specimens which seems to belong to a well-defined generic group for which the name *Hydrotribulus* has been proposed. Species of this genus have been recognized from Brightseat, Maryland and Owl Creek, Mississippi. A study of the description of a species, *Tudicla monheimi* (Müller) Holzapfel²³ from the Aachen beds of western Germany shows that the European form belongs to the same genus as the American forms and it seems advisable to propose a new genus for this group. *Hemifusus* is another genus that occurs among the Coon Creek Buccinidae and is a form which has never before been reported from the Cretaceous of Eastern United States.

In the family Nyctilochidae there is a single genus *Tritonium*. The family Columbelleriidae is represented by a

²² Harris, G. D., *Bull. Amer. Pal.*, 1896, vol. i, no. 4, p. 96, pl. 9, fig. 13.

²³ Holzapfel, E. *Palacontographica*, 1888, Band xxxiv, pag. 106, Taf. xi, figs. 4-7.

single small individual which has been assigned to the genus *Columbellina*, a group not previously reported from the Cretaceous of North America. One species of the genus *Pugnellus* of the Strombidae is very common in the Coon Creek beds. A species of *Rimella* of the same family is represented by one specimen. The family Aporrhaidae is prolific, its two genera *Aporrhais* and *Anchura* include probably nine species.

In the suborder Streptodonta the families Scalidae, Cerithiidae, Trichotropidae, Vermetidae, and Turritellidae are each represented by a single genus. In the genus *Turritella* there are probably 8 species. Both *Lunatia* and *Gyrodos* of the Naticidae are common. The individuals of one species of *Lunatia* are probably more abundant than any other gastropod species. The family Capulidae is represented by small, fragile individuals of a single species of the genus *Thylacus* which was described from Owl Creek by Conrad in 1860.²⁴ The individuals of this species are small and very fragile, yet they are abundant and perfectly preserved in their natural habitat. They occur in place fitting snugly to the columellar walls in the body cavities of larger gastropods. They have the internal muscular impression produced and leaving the wall of the shell at the anterior extremities, and lack the calcareous foot-plate characteristic of the genus *Hipponix* of this family. The family Littoriniidae is represented by the genus *Littorina* which is common in the Tertiary and Recent of the East Coast and Gulf regions, but up to the present has not been reported from the Cretaceous of these regions.

The genus *Leiostraca* of the family Eulimidae and order Aspidobranchiata is represented by abundant but often poorly preserved specimens, due to the fragility of the shell. The family Euomphalidae which is variously represented in both the Paleozoic and Mesozoic, includes a new genus *Hipocampoides*. This is a much depressed form with a pro-

²⁴ Conrad, T. A., *Jour. Acad. Nat. Sci.*, Philadelphia, 1860, vol. iv, 2d ser., p. 290, pl. 46, fig. 22.

duced keel and angular shoulder. Most of the specimens in this family that have been described from the Cretaceous of the Eastern United States have been referred to the genus *Straparollus*, and in most cases these specimens are casts and do not show any shell characters, so that it is possible that some of these casts belong to *Hippocampoides*. The family Turbinidae is herein reported from the Cretaceous of Eastern North America for the first time. This family is abundantly developed in the Paleozoic and is common in the Recent. The new genus *Schizobasis* which is characterized by a very unique, flattened notch-like anterior canal is referred after some hesitation to the family Turbinidae. The families Trochidae and Umboniidae which have representatives from the Silurian to the Recent are each represented by a genus in the Coon Creek fauna. These genera are *Solariella* and *Teinostoma* respectively and are both herein reported for the first time from the Cretaceous of North America. Another genus hitherto unknown in American Cretaceous is *Liotia* of the family Delphinulidae and in this family occurs another very abundant form at Coon Creek for which the genus *Urceolabrum* is here proposed. This seems to be a well defined generic group near *Liotia* but distinctly different from typical *Liotiae* occurring in the same strata. Besides the Coon Creek species *Urceolabrum* includes an undescribed species from Aufaula, Alabama, and another from the Aachen beds²⁵ of Vaals, Germany.

In addition to the above cited genera there are probably as many as thirteen genera of Gastropoda, including that many and more species whose generic and family relations cannot be assigned with assurance on account of their fragmentary character.

The point of greatest interest in the Coon Creek gastropods is the occurrence of eight new genera and one new subgenus, many of which are represented by more than one spe-

²⁵ Holzapfel, E., *Palaeontographica*, Band xxxiv, p. 170, Taf. xviii, figs. 3-7.

cies and also from more than one locality, as is shown in the literature by described species which have been questionably assigned generically. The genera *Solariella*, *Liotia*, *Teinostoma*, and *Columbellina* have not been previously reported from North American Cretaceous, and *Hemifusus* and *Littorina* have not been previously reported from the Cretaceous of the Eastern United States. A typical *Busycon* or *Fulgur*²⁶ is for the first time found in Cretaceous sediments. The Volutes are profusely developed, being represented by six genera and eighteen species.

Among the Cephalopods both the nautiloids and ammonoid orders are present and represented by abundant large well-preserved specimens. It is interesting to find the remains of the most primitive order of Cephalopoda which ranges from the Paleozoic to the Recent associated with abundant remains of the most highly complex and degenerate cephalopods, indicating that both thrived under the same conditions, yet the latter became extinct and the former continues to live. The family Nautilidae is represented by one species of the genus *Eutrophoceras*. The most common cephalopods at Coon Creek are the *Baculites* and *Turritiles* of the family *Lytoceratidae*. *Baculites* is profusely developed and probably includes three species. The *Cosmocerotidae* include one species of the genus *Scaphites*.

Conditions must have been especially favorable for molluscan life in the Upper Cretaceous sea in which the members of the Coon Creek assemblage grew. A glance at a tray of specimens impressed the observer with the fact that the shells are the remains of once-flourishing animals. Very many of the shells are thick, stout and of imposing dimensions. Evidently they belonged to robust, healthy and well-fed organisms. The bivalve with the greatest lateral dimensions is a species of *Inoceramus* which was probably 15 inches in maximum diameter. One species of *Cardium* is 5 inches in length

²⁶ Bruce Wade, 1917, *Am. Jour. Sci.*, vol. xliii, no. 256, p. 293, figs. 1 and 2.

and a *Cyprimeria* is $4\frac{1}{2}$ inches. *Exogyra costata* and *Gryphaea vesicularis* occur in their typical massiveness. The shells of *Cucullaea*, *Crassatellites* and *Veniella* are very abundant and evidently belonged to three very thrifty groups of Mollusca which lived under conditions especially suited to the secreting of calcium carbonate. The afflorescence of the Volutidae in the Upper Cretaceous has already been emphasized. All the species of this family are above medium size and many of them are very large. Perfect specimens of *Volutoderma* in the collection attain an altitude of half a foot. There are broken specimens which when perfect must have been almost a foot long. *Volutomorpha* is probably the giant of the Cretaceous gastropods. There is a fragment of several whorls of the spire of one species of *Volutomorpha* in the collection which would probably be 18 inches in length were the specimen complete. The genus *Ptychosyca* is large and inornate while the genus *Drilluta* is elongate and elaborately sculptured. The shells of *Pugnellus* and *Gyrodes* seem to be relics of once prosperous organisms which saw no hardships in life. *Liopeplum*, *Lunatia*, *Xancus*, *Hydrotribulus*, *Ornopsis*, etc., though less in dimensions than some of the above forms, evidently grew in very favorable environments. Species of such genera as *Columbellina*, *Solariella*, *Acteon*, *Cerithium*, etc., are much smaller in size, yet their shells are thick and stout, and no doubt grew where conditions were favorable for secreting calcium carbonate. The bivalves also show various ranges in size of thick, stout shells.

The Cephalopoda were the largest of the Coon Creek Mollusca. The genus *Eutrephoceras* is abundantly represented by large thick-shelled cavernous individuals more than six inches in diameter. One species of *Baculites* is very abundant and large. Although no complete, large individuals have been recovered from the matrix, there are several large pieces of shells and body chambers in the collection from 6 to 18 inches long and restorations of these show that some individuals were five feet in length. It should be noted here that while most of the Upper Cretaceous molluscs had thick stout

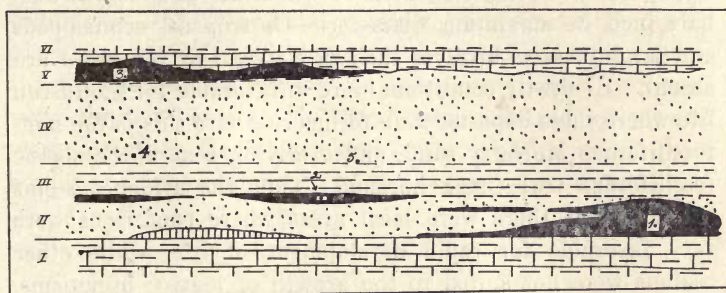
shells with coarse, vigorous ornamentation, yet many possessed small, delicate, fragile and thin shells, but have nevertheless been preserved perfectly to the present. Individuals of species of *Leda*, *Cadulus* and *Teinostoma* are smaller than a wheat grain. *Yoldia*, *Anatimya*, *Tenea*, *Liopistha*, *Leiostraca* are represented by delicate and fragile individuals. One species of *Crenella* is thinner than paper yet it is elegantly sculptured.

It is impossible to postulate with assurance the depth of the water in which the Coon Creek fauna lived. Such families as the Pernidae, Volutidae and Lytoceratidae, which are very prominent in the assemblage, are usually regarded as dwellers in the open sea at a depth of about 50 fathoms. Yet the *Nuculas*, *Corbular*, and *Naticoids*, etc., are for the most part dwellers in shallow water near shore. Lobsters and true crabs lived in great abundance in the Ripley sea as is shown by the remains of these forms which are very common in the Coon Creek sediments. There are probably five genera of the Eucrusea, among which is a large crab about seven inches across from right to left and whose modern affinities live in the intertidal zone of the seas. No foraminifera have been found. Only two very small individuals of two species of corals have been recovered. These last two facts, together with the very abundant crab remains indicate very near-shore or intertidal waters as the habitat of the Coon Creek fauna.

As regards the evidence furnished by the sediments there is no well-marked cross-bedding which would result from strong current action. However, the very presence of clastic material such as sand and clay require currents to account for transportation, and shifting of these currents to explain the intermingling of these materials. The great abundance of pelecypods which are organisms that feed for the most part on plankton is indicative of waters disturbed by currents, instead of very calm seas, for plankton occurs mostly in water that is agitated by currents. No pebbles whatever have been observed in the sediments of the Coon Creek

horizon, wood fragments are, however, common. The totality of the evidence seems to indicate that the Coon Creek fauna lived in the agitated waters near the coast of a low-lying land mass.

A study of the distribution and variation of the faunas with reference to the character of the sediments in the Ripley formation of northern Mississippi and southern Tennessee shows that the areas so favorable to molluscan life were



Diagrammatic Section SW to NE along Ripley Belt in McNairy County, Tennessee.

VI Midway Group

V Owl Creek Horizon + Northern Extension

IV McNairy Sand Member

III Ferruginous Clay Horizon

II Coon Creek Horizon

I Selma Chalk



Sandy Marl-Very fossiliferous, Coon Creek Marine Fossils

Ferruginous Clay

Gypsiferous Clay

Sand

Chalky Clay

2. Sand Hill Marine Fossils

3. Trim's Mill Marine Fossils

4. Big Cut Plants

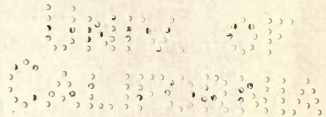
5. Selmer Plants

FIG. 2. Section of Upper Cretaceous deposits of McNairy County, Tennessee.

quite local in extent. The sediments bearing such an abundance of shells are limited both laterally and vertically in the Ripley strata and do not show a uniform wide range over a large area as is so commonly true of Paleozoic fossiliferous beds. (A diagrammatic section SW-NE across the McNairy County is shown in Fig. 2.) By tracing the Coon Creek horizons southward the plentiful shells disappear leaving in some places a very dark non-fossiliferous clay. Near Larton, McNairy County, the basal Ripley beds are represented by a glauconitic sand which contains branching remains of the so-called fucoid *Halymenites major* Lesq. This thickness of

sand extends further southward and at Sand Hill is overlain by calcareous sediments containing an unstudied fauna of probably 50 species. Three miles farther southwest there are non-fossiliferous gypsiferous clays at the base of the Ripley. Overlying the variable Coon Creek horizon is a thickness of ferruginous and micaceous Ripley clays which extends in a belt across the county. These sediments contain a sparse, dwarfed fauna of a few pelecypod genera such as *Cardium*, *Cyprimeria*, *Pecten*, etc., none of which are as much as one-half inch in maximum diameter. Gastropods, cephalopods and large massive bivalves such as *Exogyra* or *Gryphaea* are absent. Evidently conditions were unfavorable for molluscan life where these deposits were formed. Above this is the non-fossiliferous McNairy sand, and overlying that is the classic fossiliferous Owl Creek horizon. Thus the evidence seems to show that there were local areas where conditions were very favorable for rapid development of life, while other regions were not suited to the growth of marine organisms. There were probably local biological provinces which favored the development of local faunas. This may be observed in a comparison of the Owl Creek and Coon Creek faunas. Although these localities are within sixty miles of one another and in the same formation, the two faunas have a distinctly different aspect. Very many of the species are different yet many are identical. There are a number of genera from each locality not common to the other. At Owl Creek the percent of bivalve species is greater than that of the univalves, while at Coon Creek the fauna is striking for the predominance of gastropod species. The Cephalopod *Sphenodiscus* has not been found at Coon Creek while at Owl Creek it is represented by two species. As has been stated above the Owl Creek horizon is stratigraphically above the Coon Creek beds so there should be some differences in the faunas due to age but it is a question whether there should be such a striking difference in assemblages from the same formation located so near each other if such conditions as local biological provinces had not existed. It seems reason-

able to conclude from a study both of the sediments and the faunas and their distribution that, in this part of the Mississippi Embayment of the Ripley Sea, there were certain restricted areas, that were especially favorable for the growth of Mollusca. These areas were separated from one another by regions, as the sediments show, not so favorable for marine life and such regions as served to hinder free migration from one province to another. In these isolated "places of much life" variations took place due to biological and physical conditions. Environmental changes were constantly taking place due to shift and sinuosity of strand-line and change in character of sediments. In many provinces the faunas were destroyed entirely, in places some survived longer and were dwarfed, favorable places were crowded with great hordes and here evolutionary processes were most active.²⁷



²⁷ During the past winter, after the above preliminary account of the Coon Creek fauna was written, the writer has been engaged in a systematic study of the Gastropoda of this fauna in preparation of a dissertation to be submitted to the Board of University Studies. A few days collecting at Coon Creek during the summer of 1916 added many excellent and interesting specimens to the collection and the study of this material, together with that assembled in 1915, has resulted in the recognition of about 75 genera and 140 species of gastropods alone. About two-thirds of these are new species, as only about 45 species of univalves were previously known from the Cretaceous strata of the Eastern Gulf Region, and of this number only about 10 had been recognized in the State of Tennessee. It is probable that the locality is not exhausted as yet, and that further collecting, which is planned for the summer of 1917, will yield a few additional species of Gastropoda.

THE OCCURRENCE OF THE TUSCALOOSA FORMATION AS FAR NORTH AS KENTUCKY ¹

By BRUCE WADE

The Tuscaloosa formation is the basal member of the Upper Cretaceous series in the Eastern Gulf Region of the Mississippi Embayment. In Western Alabama and Eastern Mississippi this formation consists of irregularly bedded sands, clays, and gravels having an estimated total thickness of 1,000 feet. In Professional Paper 81 of the U. S. Geological Survey L. W. Stephenson has readjusted the nomenclature of the Upper Cretaceous in this region and has defined the Tuscaloosa with reference to the other formations of this series.

Toward the north the Tuscaloosa deposits become much thinner and are made up almost entirely of conglomerates which contain little sand and clay. Professor E. W. Berry has made a study of this series and has found evidence in the fossil plants that the clays, in the basal part of the formation in the region of maximum thickness, are more ancient than plant-bearing clays that occur in the conglomerates about Iuka, in northeastern Mississippi where the formation becomes much thinner. He shows that an Upper Cretaceous estuary existed for a long time in Western Alabama before it transgressed into the northern part of Mississippi and Alabama.

Until recently the Tuscaloosa formation was thought to thin out entirely in the vicinity of the Tennessee-Alabama line. In 1913 H. D. Miser mapped the areal geology of the Waynesboro Quadrangle of Tennessee and found that the Tuscaloosa was 150 feet ² thick and extended over a large part of Wayne County. Subsequent work by the Tennessee Geologi-

¹ Published with the permission of Dr. A. H. Purdue, State Geologist of Tennessee.

² Miser, H. D., "Economic Geology of the Waynesboro Quadrangle," Resources of Tennessee, 1913, vol. iv, no. 3, p. 107.

cal Survey showed that remnants of the Tuscaloosa gravel occur in place on the Highland Rim of Tennessee as far north as the northern Lewis County.³ Farther north, during the past summer, the writer encountered undescribed occurrences of the Tuscaloosa formation which show that the sediments of this transgressive phase of the Upper Cretaceous exist in a chain of local outlying areas across the State of Tennessee and as far north as the ridge west of Canton, Kentucky.

An important link in this chain are the gravels which occur locally along the Nashville, Chattanooga and St. Louis Railroad between McEwen and Tennessee City and capping the higher hills in this part of Dickson County, Tennessee. A cut on the railroad about two miles east of McEwen shows, resting on chert of the St. Louis formation, about 30 feet of very compact hard white chert gravel which is very typical of the Tuscaloosa belt across the State. No paleontological evidence has been obtained from the gravels about McEwen to determine the age of these deposits, but after a study of the lithology as well as the geographic and topographic relations, the Tuscaloosa age of the McEwen gravels can hardly be doubted. These gravels are made up of well rounded water worn pebbles, most of which are one inch or less in diameter, although many are larger, often ranging up to cobbles six inches in diameter. Many individuals approach a sphere in outline and in this respect they differ from the river gravels which are common in terraces along the Western Tennessee Valley. In the river gravels of this region the individuals are often flat, elongated, and subangular. Small discoidal quartzite pebbles are often conspicuous in the terrace conglomerates. The Tuscaloosa conglomerates consist for the most part of pebbles and boulders derived from the Lower Carboniferous cherts which are common in this part of the Mississippi basin. Water worn sandstone and

³ Wade, Bruce, "Geology of Perry County and Vicinity." Resources of Tennessee, 1914, vol. iv, no. 4, p. 173.

iron oxide pebbles have not been observed in the Tuscaloosa. This is another feature which serves to distinguish the Upper Cretaceous gravels from the more recent terrace gravels in this part of the Embayment Region, even though the latter may rest directly on the former as is frequently the case in the Western Tennessee Valley.

South of McEwen, as stated above, the isolated Tuscaloosa gravel areas may be traced along the Highland Rim across Lewis County into Wayne and Hardin Counties and farther into Mississippi and Alabama where they are overlain by marine Eutaw deposits and consequently paleontologic evidence may be obtained.

The Tuscaloosa extends also north of McEwen. About 3 miles west of Canton in Trigg County, Kentucky, at a point just east of where the Fulton and Nashville Highway crosses the divide between the Tennessee and Cumberland Rivers is an exposure of Upper Cretaceous which has not heretofore been reported. The locality is about 7 miles each of the Upper Cretaceous belt as shown by the Geological Map of Kentucky.⁴ At this locality the following section may be observed:

River Terrace,	sandy clay and leached soil which becomes thicker $\frac{1}{4}$ mile to the west where it contains thick beds of ferruginous conglomerate..	O — 12 ft.
Eutaw,	red micaceous sand containing streaks and pellets of white clay and remains of <i>Halymenites major</i> Lesquereux.....	O — 10 $\frac{1}{2}$ ft.
Tuscaloosa,	well rounded white chert pebbles and cobbles. The base of the Tuscaloosa was not exposed here but Mississippian chert occurs in place some distance below in the hollow leading northward.....	+ 31 ft.

⁴ Sellier, L. M. "State Geological Map." Kentucky Geological Survey, 1915.

The above section occurs in the top of the divide which is probably more than 300 feet above the waters of the Tennessee and Cumberland Rivers. This divide is a northern extension of the Western Highland Rim of Tennessee and it is probable that further study of the plateau between the

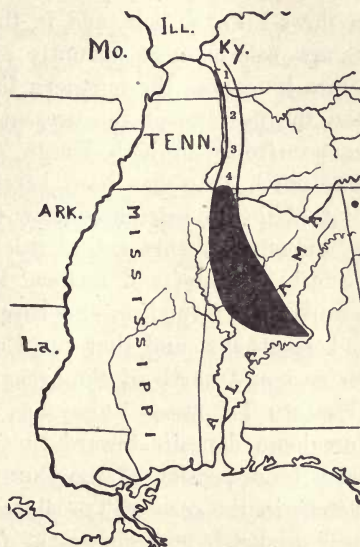


FIG. 1.

Sketch map of the Eastern Gulf area showing the northward extension of the Tuscaloosa formation from the previously mapped area in solid black.

- 1.—Section in Trigg County.
- 2.—Section in Dickson County.
- 3.—Section in Lewis County.
- 4.—Section in Wayne County.

Canton and McEwen localities will reveal isolated occurrences of Tuscaloosa that form an almost unbroken chain of the remnants of this formation from Kentucky across Tennessee into Mississippi and Alabama.

A study of a map⁵ of the Upper Cretaceous belt of the

⁵ Stephenson, L. W., "Cretaceous Deposits of the Eastern Gulf Region." U. S. Geological Survey, 1914, Professional Paper 81, map.

Eastern Gulf Region shows that the Tennessee River flows from the east into the Cretaceous in northwestern Alabama and then takes a northerly course just east of the Cretaceous across Tennessee and Kentucky. The geological map shows that the wide Tuscaloosa belt in Western Alabama and Eastern Mississippi disappears entirely just north of where the Tennessee River flows into the belt, and in the same part of the state the Eutaw belt becomes abruptly narrow and disappears long before it reaches the northern limit of Tennessee. It has been the purpose of the present article to call attention to the occurrence of both Eutaw and Tuscaloosa sediments farther north than has been heretofore reported and to point out that these occurrences show that the Tuscaloosa formation, though probably not as thick and as widespread as in Western Alabama and Eastern Mississippi, was at one time an important formation and covered large areas in Tennessee and Kentucky, and that the Eutaw formation extended farther east and north of the areas mapped. The erosion of the Western Tennessee Valley has almost entirely removed the Tuscaloosa deposits toward the north, and has likewise removed a large portion of the Eutaw deposits, but to a less extent than in the case of Tuscaloosa.

The accompanying sketch map shows the formerly known distribution of the Tuscaloosa in Eastern Mississippi and Western Alabama and the probable northward extension of the Tuscaloosa belt as shown by the recent work in this area.

THE HABITAT OF BELEMNITELLA AMERICANA AND MUCRONATA

By GEO. EDWIN DORSEY

The question as to whether or not the almost cosmopolitan range of certain type fossils is an indication of similar life conditions over wide areas, or to what extent it may indicate especially hardy, easily or rapidly adaptable organisms, has never been tested. Presumably in the case of some organisms cosmopolitanism is attained because of the wide extent of favorable environments, while in the case of other organisms they are less affected by the environment or more adaptable to it.

With the idea of ascertaining whether similar conditions of deposition of the fossiliferous sediments as evidenced by identical or similar lithology can be correlated with the occurrence of particular species of wide-ranging fossils, I have taken the form *Belemnitella americana* with its European analogue, *Belemnitella mucronata*, and have searched the literature with regard to their occurrence and the character of the sediments in which they are found. The result is very interesting and fairly conclusive.

To anticipate these results I have found that in almost every instance where these types are found, they are associated with a lithology which indicates practically identical conditions of deposition. On the other hand, and as a corollary to this fact, they show no evidence of adaptation. These species appear with unusual suddenness and abundance toward the top of the Upper Cretaceous, spread rapidly and to great distances, and die out before the dawn of the Tertiary as abruptly as they appeared. Throughout this comparatively short period geologically they apparently maintain a rigidly uncompromising individuality. However, the fact that the fossil form called *Belemnitella* is merely a small internal vestige of a once-enveloping shell, and hence far

from a trustworthy guide to the adaptable characteristics of the form, vitiates to a certain extent any general conclusions, such as that wide-spread occurrences of type fossils indicate correspondingly widespread similarity of life conditions. Nevertheless, the apparent inability of these *Belemnitellas* to live except in a certain, rather fixed environment, is at least suggestive that their powers of adaptation were limited.

Whitfield (1) describing the American species writes as follows:

"Stylet or guard, rather large, solid, and heavy, often becoming thickened with age. Specimens varying from nearly 3 inches to nearly 4 inches in length below the base of the slit, the larger ones evidently having a length of fully 6 inches, from the lower extremity to the top of the internal cavity, or conotheca. General form triangularly cylindrical in the upper part, becoming flattened on the ventral side in the lower part, with frequently a slight mucronate extremity. . . . The upper end of the stylet or guard, from about the base of the internal cavity, gradually expands upward, and becomes very thin on the edge, and the inner surface of the wall often bears the marks of the transverse septa of the phragmacone. The entire surface is usually much roughened when not worn, the roughening being greatest on the ventral side, while laterally this roughening produces vascular lines running obliquely backward, in crossing from the ventral to the dorsal surfaces, and on the raised lanceolate area of the dorsal surface the markings are finer and arranged so as to produce longitudinal lines, or interrupted striae."

There seems to be a fair degree of unanimity as to the similarity of *B. americana* (Morton) and the European form, *B. mucronata*, D'Orbigny. Morton says (2, p. 190).

"This species has an analogue in the *B. mucronata* of Schlotheim, which is characteristic of the Chalk throughout Europe. It seems also to resemble the belemnite of Maestricht, as figured by Faujas."

D'Orbigny, (3, p. 63-4) describes the European form as follows:

"Rostré allongé, quelquefois un peu comprimé, cylindrique sur sa moitié antérieure, de là acuminé jusqu'à l'extrémité très-obtuse, au milieu de laquelle est une pointe souvent assez allongée; les deux impressions dorsales sont très marquées, large, et il en part des petits sillons ramifiés et réticulés, qui viennent joindre le partie in-

férieure. Scissure long, occupant la moitié de la cavité. Cavité ronde, très-longue, conique, occupant les deux cinquièmes de la longueur, pourvues en dessus d'un sillon creux longitudinal; alvéole avec des cloisons séparées, dont les traces se montrent encore dans la cavité. Jeune, sa form est plus conique et légèrement comprimée."

Despite the fact that *B. americana* and *B. mucronata* are regarded as type fossils, and that the two forms are regarded as closely related, they do not represent exactly the same horizons on both sides of the Atlantic, the American form being somewhat older than its European analogue.

One of the typical American occurrences is in the Monmouth formation of the Upper Cretaceous of New Jersey. J. A. Gardner (4, p. 396) says,

"It (*B. americana*) is perhaps the most valuable horizon marker of the Cretaceous, since it has never been reported from either above or below the Monmouth, and is determinable from the merest fragment."

The Monmouth formation, whose type locality is in Monmouth County, New Jersey, has been divided by W. B. Clark, in ascending order, into the Mt. Laurel sands, the Navesink marls, and the Redbank sands. The *Belemnitella* zone in New Jersey occurs at the Navesink marl level and thus is about midway in the Monmouth. To the south, *B. americana* is found in the Peedee formation of North and South Carolina, and farther to the south in the *Exogyra costata* zone of the Selma Chalk.

It apparently dies out before the deposition of the upper Monmouth. In Europe, *B. mucronata* is first found in the late Campanian. It continues throughout the Maestrichtian, that is throughout the Aturian or uppermost Senonian. The overlying Danian from which it is absent is correlated with the New Jersey Rancocas and Manasquan formations. Thus, if, as Clark says (4, p. 74), "The (Monmouth) forms point to the lower Senonian age of the beds," then the presence of *B. mucronata* in the Maestrichtian is decidedly younger, particularly so since *Belemnitella* is not present in America even in late Monmouth time.

The striking fact about both the American and European occurrences is that *B. americana* and *B. mucronata* are practically always found in "greensand," of a very glauconitic nature, or in chalk. The explanation of this rather unexpected uniformity will be discussed after a brief review of the occurrences on the two continents.

The marine Upper Cretaceous of North America is not found farther north along the Atlantic coast than Long Island where, however, only the earlier horizons are represented. M. L. Fuller (5, p. 77) says that well-borings are sufficiently numerous to make it perfectly clear that there are, on Long Island, no thick greensand beds like those in New Jersey, their stratigraphic position being occupied by sands. A reference to his list of Cretaceous fossils (p. 78), reveals the entire absence of *B. americana* from all of these beds.

As noted above, the Navesink marls of New Jersey are the most northern occurrence of *B. americana*. This member, representing the middle Monmouth formations of New Jersey and Maryland, embraces the Lower Marl Bed of Cook, concerning which, W. B. Clark writes (6, p. 191): "The lower Marl Bed is a characteristic greensand, glauconite entering to a marked extent into its composition." The same author (7, p. 334) writes of this formation, "The Navesink marls are typically glauconitic sands. . . . The basal portion consists generally of arenaceous beds that have been hitherto referred to under the name of sand marl. Above the sand marl in the northern portion of the area, is a very compact blue marl, which is highly glauconitic, and frequently fossiliferous in its central portions."

The Monmouth formation reappears in Delaware and Maryland, where it has lost the three-fold characteristic of the New Jersey section. As the beds appear in northeastern Maryland and Delaware they still preserve their remarkably glauconitic character. Clark (4, p. 70) says, "The Monmouth formation consists chiefly of reddish and pinkish sands, generally glauconitic, the beds in places forming a dark

greensand." This is true to a marked extent for only the beds along Bohemia Creek in Maryland, in the northeastern part of the state. The Monmouth, as it occurs on the Western shore of the state, from Anne Arundel to Prince George's county, has lost the markedly glauconitic character of the Bohemia Creek facies,—clays and muds being considerably more prominent. It is especially significant, in view of the above, that we find *B. americana* in abundance on the Eastern shore in the glauconite, and no trace of it on the Western shore in the muds and clays.

Weller (22, p. 18) has called attention to the fact that the Redbank sands of New Jersey pinch out passing to the southwest, their stratigraphic position being occupied by the Navesink marls which here still maintain their glauconitic facies. Accordingly, as one progresses toward Delaware and Maryland from Long Island, he passes through a series that is progressively more glauconitic, until over southwestern New Jersey, Delaware, and northeastern Maryland is located the greatest development of this facies. Still farther toward the southwest, the greensand aspect gives way to muds and clays, until one reaches the Virginia land mass. This points pretty definitely to the existence of a basin in which glauconite was being deposited, far enough removed from land, or with such a slight influx of terrigenous materials, as to give clear, quiet waters, during a large part of Monmouth time.

As noted above, Virginia was above water during the Monmouth, but in North Carolina, in the so-called Peedee sands of Ruffin, we have conditions of sedimentation almost identical with those of the New Jersey-Delaware-Maryland Monmouth,—a series of alternating sands and clays, the sands being highly glauconitic. According to Stephenson (8, p. 146), "The content of glauconite in the greensands of North Carolina appears to be less than that of the greensand marls of New Jersey." A careful study of the sections of those localities at which *B. americana* is found, reveals, without exception the highly glauconitic nature of the fossil-bearing

beds. A few examples may be selected at random, *B. americana* being recorded from each locality (8):

U. S. GEOLOGICAL SURVEY, LOCATION 4133 (p. 153)

Pleistocene	
Loose, light sand.....	6 ft.
Unconformity	
Cretaceous (Peedee sand)	
Firmly indurated, dark gray, calcareous, glauconitic sand, containing many fossils.....	2 ft.
Dark green, argillaceous, micaceous, rather coarse sand, containing a few fossils.....	7 ft.

U. S. G. S. LOCATION 4130 (p. 154)

Pleistocene	
Loose white sand.....	8 ft.
Unconformity	
Cretaceous (Peedee sand)	
Dark green, glauconitic sand.....	1 ft.
Greenish gray, glauconitic and calcareous sandstone, containing numerous fossils.....	1½ ft.
Dark greenish gray glauconitic sand, containing a few fossils	2 ft.

U. S. G. S. LOCATIONS NOS. 4169 AND 4137 (p. 157)

Pleistocene	
Sand and loam poorly exposed.....	15 ft.
Eocene	
Thin-bedded shale with conglomerate band at base..	7 ft.
Unconformity	
Cretaceous (Peedee sand)	
Dark green, very compact, arenaceous, glauconitic, micaceous clay, containing numerous shells and casts	11 ft.
Concealed, to waters edge.....	3 ft.

The report states that from this locality the *B. americana* were collected from the greensand.

This series of sections, illustrating the association of greensand with the *Belemnitella* remains, could be continued until every locality was listed. There are localities given, where, in the Peedee greensands, no remains of *Belemnitella* have been recovered. But this can not be regarded as evidence of any kind. The fact that *B. americana* lived only under conditions

where glauconitic deposition could take place, does not necessarily imply that it lived everywhere where such conditions existed, any more than its isolated occurrence in beds of neither a glauconitic nor a chalky phase proves that the constant association with such phases is of no significance. The close proximity of the localities in the Carolinas, however, and the evidence in favor of fairly widespread similar conditions during Peedee time point rather to incomplete fossil collections than to absence of the form.

Passing to the south, and southwest, the horizon of the Monmouth, marked by greensands thus far, gives way to chalk. The Selma Chalk, the time equivalent of part of the Ripley, is the next source of *B. americana*. The greatest development of the Selma Chalk is in central and western Alabama, and in east-central Mississippi. To the north in Mississippi the Chalk thins rapidly and becomes very argillaceous, and in Tennessee is a very thin basal layer of the Ripley formation. An examination of the tables of species prepared by L. W. Stephenson (9, facing p. 24) reveals the widespread occurrence of *B. americana* in the Selma Chalk. Thus in east central Mississippi and adjacent parts of Alabama, it is recorded from 9 localities; in the region of Warrior and Tombigbee rivers, Alabama, from 2 localities; from the vicinity of the Alabama River, Alabama, from 2 localities. About a quarter of a mile east of Troy, Mississippi, an occurrence of *B. americana* is recorded at about the juncture of the Selma and the Ripley (U. S. G. S. Location 6471); and in the northern Mississippi area (N. E. $\frac{1}{4}$ Sec. 14, T. 4 S., R. 5 E., at U. S. G. S. Location 544) the form has been recorded in the Ripley formation; and there is no record of its occurrence in the Selma Chalk proper in either of these immediate regions. Inasmuch as *B. americana* occurs over this large area, practically everywhere in the Selma Chalk, which "consists in the main of more or less argillaceous and sandy limestones, rendered chalky by their large content of Foraminiferal remains, with interbedded layers of nearly pure,

hard limestones at wide intervals," and as chalk has been found to be one of the two facies in which *B. americana* practically always occurs, the various localities need not be considered in detail. In the case of the two Ripley occurrences, however, the lithology must be examined.

Dr. L. W. Stephenson, of the U. S. Geological Survey, has kindly furnished me with the following information in regard to these occurrences. The locality one-quarter mile east of Troy, Mississippi, came from a "gray, highly calcareous sandstone," of which Dr. Stephenson sent me a sample. The rock bears not the slightest trace of glauconitic material, but is composed to a very large degree of limestone, of a chalky character. In places the sand grains,—milky quartz,—are embedded in a solid calcareous matrix. Thus, while not perhaps occurring in the Selma Chalk proper, the lithology of the beds may be regarded as identical with that of many parts of the Chalk formation. Of location 544, in Tippah County, Mississippi, Dr. Stephenson says, "the matrix attached to one specimen in the lot is gray, calcareous, glauconitic (?) sand." This specimen is a *Serpula*. He does not go into further detail regarding the locality, but it may be a fair inference, despite a warning that some of this material may be mixed, that glauconite was present at least in the vicinity of this occurrence of *B. americana*. It is rather significant in this connection to note that the glauconite locality was in the true Ripley, at some distance from the Selma Chalk, and the non-glauconitic, but highly calcareous facies, was very near to the contact of the Selma and Ripley.

The most noteworthy gap in the range of *B. americana* in the southeastern United States is in Georgia. Here the Ripley formation is well developed, attaining a maximum thickness of about 850 feet, but nowhere in the large area covered by the formation, which at times is somewhat glauconitic, is *B. americana* recorded. The many sections of the Ripley given by Veatch and Stephenson (10), and the numerous fossil collections, never mention *B. americana*. This is probably due to the Georgian Ripley being a nearer-shore

deposit than the Selma or the Ripley to the west. Throughout the Ripley in Georgia are found remains of plants and lignite, clearly pointing to an estuarine or very near-shore origin. On the other hand, Professor E. W. Berry has informed me that to his knowledge there has never been a piece of lignite found in the Chalk. The grading of the Chalk, to the east, into sands and muds, is thus to be taken as indicating an approach to land, and hence to comparatively muddy waters, which we shall see were intolerable surroundings for this species.

This list of occurrences exhausts the localities for *B. americana*. It is restricted to the Atlantic and Eastern Gulf provinces of the United States,—occurring at the Monmouth or *Exogyra costata* level of the Upper Cretaceous along the Atlantic coast and in the eastern part of the Mississippi Embayment. The generalization that *B. americana* occurs mainly in a chalky or a glauconitic-greensand facies will be seen to hold true to a remarkable extent throughout this range. Although absent in many instances in favorable lithology, I have yet to discover an occurrence in a facies radically different from the above.

The European occurrences of the form, known as *Belemnitella mucronata*, D'Orbigny, conform in every way to the restrictions in lithologic characteristics imposed by *B. americana*. As noted elsewhere, the European horizons at which *B. mucronata* occurs are slightly younger than the American. We first observe its presence in the uppermost Campanian, but it is the Maestrichtian that witnesses its widespread distribution. A glance at a map (e. g., Haug, 13, p. 1299) showing the distribution of the various Neocretaceous deposits will show that the occurrence of chalk is, broadly, in a northwest-southeast belt, from Antrim in Ireland, across England, into Germany and Poland, and along the eastern front of the Carpathian Mountains, with large areas in central and eastern Russia, and the Caucasus and Trans-Caucasus. Southwest from this main basin, from Sweden through eastern France, is a subordinate trough, with a few isolated

localities in west France, in Charente, these two basins forming the legs of a triangle; and finally, eastward from the southern limit of this trough, across the present site of the Alps, connecting the two legs of the triangle is a subordinate basin, in which marls and limestones were deposited, connecting with the basin of Russia.

This rough triangle around Germany left the greater part of the German Empire above water during late Senonian time. A. R. Wallace (15, p. 91) quotes Sir Charles Lyell as follows, "pure chalk, of nearly uniform aspect and composition is met with in a northwest and southeast direction, from the north of Ireland to the Crimea, a distance of about 1140 geographical miles; and in an opposite direction it extends from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles." Wallace goes on to say that, while this marks the extreme limits within which true chalk is found, "the chalk is by no means continuous. It probably implies, however, the existence across central Europe of a sea somewhat larger than the Mediterranean."

The most widespread and the most typical chalks of Upper Cretaceous age are those represented by the Upper Chalk of England, and its equivalents, the Campanian and Maestrichtian, of the continent. In northeastern Ireland, in Antrim, under a Tertiary basaltic flow, resting unconformably on Liassic and Rhaetic strata, Jukes-Brown (11, p. 322) gives the following series, all of Upper Chalk age:—

- | | |
|--|---------|
| 3. White limestone, with <i>B. mucronata</i> | 100 ft. |
| 2. Hard, pinkish, glauconitic limestone, with quartz grains, and phosphatic nodules..... | 4 ft. |
| 1. Glauconitic limestone, passing down into glauconitic sand | 16 ft. |

Geikie (12, p. 1194) refers to this series as "Hard white chalk, 65 to 200 feet, with *Echinocorys* [*Ananchytes*] *sulcatus*, etc.=Zone of *B. mucronata*." Very little referable to the Upper Chalk remains in Scotland, but in the west, under the volcanic plateaus of Mull and Morven, some of the

Upper Chalk is found. Jukes-Brown (11, p. 322) says regarding this, "The white sandstones of the west coast are overlain by a few feet of argillaceous greensand, passing up into glauconitic limestone, the two being only five to seven feet thick. . . . Above these is a bed of white *B. mucronata* chalk, from three to ten feet thick, which is evidently a mere remnant of a much thicker deposit."

In England, the Belemnitella zone of the Upper Chalk has been traced from Kent to Dorset, along the Channel, and thence northeastward to Norfolk. It reaches a thickness of 100-160 feet in the Hampshire basin, and in Norfolk it attains its maximum development. Near Norwich, Geikie (12, p. 1193) describes it as a "white, crumbling chalk, with layers of black flints, which have yielded abundant sponge spicules." Everywhere in the British Isles where *B. mucronata* has been found, it has been in a pronouncedly chalky matrix.

On the continent, around the eastern shores of the Baltic, the Senonian is present as white cliffs, in Pomerania, in Rügen, along the south shores of Sweden, and the Danish islands. It is also present in Lünberg in east Prussia. While some *B. mucronata* are recorded in the Campanian (Haug, 13, p. 1301), it is first mentioned in this region in the upper Maestrichtian, in a lithology of persistent white chalk. Haug remarks in connection with this occurrence that as in the Paris Basin, the ammonites are rare, and one is certainly in the presence of deposits of shallower seas than those over Hannover and Westphalia. *Ananchytes ovatus*, *Magas pumilis*, and *Terebratula carnea* are abundantly associated with the Belemnitellas.

Passing to the vicinity of the Anglo-Parisian Basin, we find in the neighborhood of Lille, and in the province of Hainaut in Belgium, the Campanian very slightly fossiliferous, but the Maestrichtian well represented by six zones, according to Haug (13, p. 1302-3), in every one of which *B. mucronata* is recorded. The lithology varies from a phosphatic conglomerate at the base, with broken remains of *B.*

mucronata, through chalks of varying degrees of purity, with an occasional conglomerate intercalated, to the basal conglomerate of the "tuffeau de Ciply," which transgresses the two upper zones of the Maestrichtian proper. In the province of Limburg, in Belgium, the Campanian, though glauconitic, has not as yet yielded any *Belemnitellas*; but the Maestrichtian, here divided into five zones, contains *B. mucronata* throughout. It is worth while looking at the lithology of each of these for a moment (13, p. 1303-4) :—

Zone 1—(oldest) Glauconitic chalk with *B. mucronata*.

Zone 2—Pure white or marly gray chalk, without flints, with *B. mucronata*.

Zone 3—Thick white chalk with black flints, with *B. mucronata*, grading off laterally into the Kunraed limestone,—marly, gray, very fossiliferous, but no *B. mucronata*.

Zone 4—Tuffs, with gray flints, with *B. mucronata*.

Zone 5—Tuffs, with numerous gastropods, and a few cephalopods, among these being *B. mucronata*.

Haug, referring to this succession (p. 1304), says the Maestrichtian of Limburg is essentially a neritic formation, offering few or no paleontologic affinities with the bathyal type of the stage, such as existed in the northeast of Germany.

In the Paris Basin, proper, the Upper Senonian is divided according to Grossouvre, into the following:

Campanian

Zone 1—Gray chalk of Hardivillers.

Zone 2—Upper Chalk of Reims, White Chalk of Hardivillers, and Chalk of Michery, with *B. mucronata*.

Maestrichtian (craie de *B. mucronata*) Chalk of Meudon, of Monterau, and of St. Aignan, with *B. mucronata*.

The fauna of the chalk of Meudon is very rich, but ammonites are rare in it, while *Inoceramus*, *Pecten*, *Ostrea*, and *Brachipoda* are well represented. In the southern part of the Paris Basin the Maestrichtian is represented by only its lower beds, the time of the typical Maestrichtian of the northeast being a period of emergence in this region. In Normandy, however, the Maestrichtian is the only member

of the Senonian present. Here it is a sandy, chalky deposit, and contains great numbers of fossils, *B. mucronata* among them. This occurrence is very similar to the Maestrichtian of the Baltic provinces and Belgium.

In the Aquitanian region, conditions similar to those in Touraine prevailed, except that here the Campanian in Charente does not carry *B. mucronata* at all, and the Maestrichtian, divisible into three zones, is present in its entirety. But only in the lowest zone—a white limestone, with bryozoa, oysters, etc.,—is *B. mucronata* found. The upper two, consisting of ferruginous sands and yellow limestones are probably too littoral in character to contain *B. mucronata*. Haug calls the Charentian-Senonian neritic. In the south, in the vicinity of Lyons, the Senonian,—here apparently undifferentiated—rests upon the Albian, and contains *B. mucronata* and *Ananchytes ovatus*. The matrix is a grayish white limestone. Similarly, in the Alps, at Geneva, in a marly, gray limestone, with siliceous beds of Foraminifera in the upper part, the undifferentiated Senonian rests upon the Albian, and contains *B. mucronata*, with *Ananchytes ovatus*, and some Inocerami. Both of these occurrences are questionably referred to the Maestrichtian.

From the region of Lake Geneva, the Senonian deposits occur in a narrow strip across the Alps, being especially well studied in the northern and eastern Alpine regions. At Tolz, in Bavaria, there is a greensand, containing sponges, gastropods, and *B. mucronata*. Between Bergen and Teisendorf, in the same region, are forms like the neritic species of the Maestrichtian of Limburg, in a great thickness of marls containing *B. mucronata* near the top. North of Salzburg, in western Austria-Hungary, the Senonian, composed largely of marls, contains *B. mucronata*.

The “couches de Gosau,” a name applied to a series of conglomeratic and marly beds south of Salzburg, in the province of Salzburg, is divided into five zones, the uppermost of which, the marly “couches de Nierenthal,” contain *B. mucronata* and are correlated with the Maestrichtian. In

the southern Alps, *B. mucronata* occurs in a thick series of marly limestones, with a fauna composed of pelycypods and cephalopods, known as "l'étage de Brenno."

In the East Russia-Poland-Carpathian region, the chalk covers vast areas, and everywhere has the same facies as that of the Anglo-Parisian Basin and north Germany. Over Poland and East Russia the greater part of the fossils come from the Maestrichtian, which is a typical chalk. To the south, although the Maestrichtian is present over large areas, its facies has so changed (to sands and clays) that *B. mucronata* is rarely present. When, however, we do find it, the accompanying lithology is unchanged. In the Bulgarian plateau and the Dobrudja, there is a thick series of Senonian age, whose upper part is composed of white, porous limestones, with siliceous lenses,—in every way, Haug says, like the Anglo-Parisian Maestrichtian, and here we find *B. mucronata*. In the Crimea, the Campanian and lower Maestrichtian are composed of white chalk, in which *B. mucronata* is present. The Senonian of the Caucasus is usually a white chalk, very similar to that of the Anglo-Parisian basin, and with *B. mucronata*. Near Toupiniza, in Servia, an occurrence of *B. mucronata* is mentioned in marly sands, but this is very near the region of the Dinaric Alps, where the chalky limestone facies, which is characteristic of the Maestrichtian in most of eastern Europe, is absent. The geology of Croatia, Dalmatia, and Bosnia is in such an unknown condition, that exactly what is present can not be said, but no record of *B. mucronata* was found.

Passing from the Balkans, the next, and last, occurrence of *B. mucronata* is in the Magishlak peninsula, on the north-east coast of the Caspian Sea. Here the following beds are differentiated (13, p. 1337):—

Zone 1—A white chalk, with *Ananchytes ovatus*, *Inoceramus balticus*, *Pycnodonta vesicularis*, *Belemnitella mucronata*.

Zone 2—A marly and glauconitic chalk, with *Ananchytes ovatus*, *Magas pumilis*, *Pycnodonta vesicularis*, *Scaphites schluteri*, *Hamites roemeri*, *B. mucronata*.

Zone 3—Some limestone, with *Echinoconus conicus*, *Ananchytes ovatus*, *Scaphites constrictus*, *Baculites incurvatus*.

Zone 4—Some marly sands, with *Ananchytes sulcatus*, *Terebratula fallax*, and *faxoensis*, *Pycnodonta vesicularis*.

The above is a good example of what is continually being repeated in the recorded occurrences of this *Belemnitella* form. Where there is a chalky or a glauconitic facies the form is present. When this changes to anything else, it is almost invariably absent.

The most prominent exception to this, as will be seen from the facies given above, is the area across the Alps,—the basin connecting the two main basins from England to Russia and from Sweden to France. Here *B. mucronata* occurs most often in a marly or marly limestone facies. It is likely that most of the surrounding country in the late Senonian was peneplained, which would permit clear water in very near shore deposits, and explain the occurrence of limestone with marls. If *B. mucronata*, ranging far and wide over areas in which chalk was being deposited were to stray into this basin, open to the two regions of congenial habitat, they might either pass through to the far basin, or die on the way. If such a condition had existed we should expect to find the form exactly as we do find it, erratically distributed in changing lithology.

If we pursue our search for *B. mucronata* farther to the east, into Persia, Turkestan, Siberia, China, Japan, Alaska, we everywhere find it absent. Although the Senonian is present in much of this area, there are no occurrences of *B. mucronata* recorded.

The Senonian, as it occurs around the western shores of the Mediterranean Sea, will afford a rather impressive illustration of the way in which, with a change in the facies of the beds, *B. mucronata* vanishes. In Sicily, and in Spain, the Senonian is present as sands with occasional limy lenses. In Italy the Hippurites limestone is well developed. In Tunis the late Cretaceous is represented by white limestones, alternating with yellow marls. In the south of Tunis there is also a very well

known fauna, from a great thickness of Senonian, in which all stages have been differentiated. In Morocco there is less known about the Senonian, but in all of these occurrences *B. mucronata* is noticeable only by its absence. In Egypt the Campanian and Maestrichtian are very well developed, the latter becoming thicker as it passes southward. In the north, it contains oysters and *Exogyra overwegi*; to the south, where the facies is one of ferruginous sands, and gypseous and salt-bearing clays, attaining a thickness of 150 meters, Zittel has recorded a very large fauna, with no *B. mucronata*.

Such negative evidence could be continued indefinitely, always affording striking corroboration of the evidence afforded by its occurrence. I do not see how it is possible to escape the conclusion that there is undoubtedly some connection between the conditions under which glauconite and chalk were deposited, and endurable life conditions for *B. mucronata* and *B. americana*. Also, the abruptness with which they disappear when any other facies occurs seems to indicate a very restricted power of adaptation. Does their occurrence in glauconitic sands and chalk indicate the maximum effort of this limited power of adaptation under two different conditions of life, or do the glauconite and chalk mean practically identical conditions of deposition? The latter, in the light of the most recent interpretation of these facies, is to be regarded as the correct conclusion.

The bathymetric conditions under which chalk was laid down have been the source of much speculation, which has gradually undergone a most marked change. The venerable and orthodox idea is that the chalk is a deposit formed in a large ocean at great depths,—that it is an abyssal deposit comparable to the Globigerina-ooze of recent seas. The large proportion of Foraminifera was regarded as proof of this. Cayeux (14, p. 523-4) give a résumé of the various expressions of opinion on the origin of chalk, dating from 1833 to the end of the nineteenth century. Mantell, in 1833, and R. A. C. Austin in 1843, both postulate abyssal conditions. Goodwin-Austin in 1858 writes that A. D'Orbigny and E. Forbes

believe in the deep-sea origin of chalk, and he adds that the organic remains in the chalk were carried there by currents from regions of shallower water. In 1863 Hébert said the chalk of the Paris Basin was formed at a sufficiently shallow depth for it to take part in a period of emergence, being the first hint that chalk might not be abyssal. Delesse was the first to introduce warmth as one of the requisites for chalk deposition, when he said, in 1866, that the water of the Paris Basin was of the same temperature as that of the Gulf Stream today. Then followed in order, W. Thompson, Prestwich, Whitaker, M. J. Murray, all subscribing to the deep-sea origin. In 1877 the first discordant note was sounded by Gwyn-Jeffreys, who declared the molluscs of the chalk were shallow water and tropical forms. A. Geikie, in 1879, supported this idea. Sollas says the sponges indicate a depth of 100-400 fathoms. Lambert, and Prestwich in a later article, Peron, Neumayr, Agassiz, and Jukes-Brown have all held that the chalk was formed in deep waters. But the many indications of emergence that have been found associated with the chalk throughout Europe, and the absence in the main of any organisms that can only be abyssal, have caused most present-day geologists to abandon this idea. A. R. Wallace (15, p. 87, *et seq.*), in 1880, discusses the origin of chalk as follows:

“There seems very good reason to believe that few, if any, of the rocks known to the geologists correspond exactly to the deposits now forming at the bottom of our great oceans. The white oceanic mud, or Globigerina-ooze, found in all of the great oceans at depths varying from 250 to nearly 3,000 fathoms, and almost constantly in depths under 2,000 fathoms, has, however, been supposed to be an exception, and to correspond exactly to our white and gray chalk. This view has been adopted chiefly on account of the similarity of the minute organisms found to compose a considerable portion of both deposits, more especially the pelagic Foraminifera, of which several species of Globigerina appear to be identical in the chalk and the modern Atlantic mud. . . . Now as some explanation of the origin of chalk had long been desired by geologists, it is not surprising that the amount of resemblance shown to exist between it and some kinds of oceanic mud should at once have been seized upon,

and the conclusion arrived at that chalk is a deep-sea oceanic formation exactly analogous to that which has been shown to cover large areas of the Atlantic, Pacific, and Southern oceans.

"But there are several objections to this view which seem fatal to its acceptance. In the first place, no specimens of Globigerina-ooze from the deep ocean-bed yet examined agree even approximately with chalk in chemical composition, only containing from 44 per cent. to 79 per cent. of carbonate of lime, with from 5 per cent. to 11 per cent. of silica, and from 8 per cent. to 33 per cent. of alumina and oxide of iron. Chalk on the other hand contains usually from 94 per cent. to 99 per cent. of carbonate of lime, and a very minute quantity of alumina and silica. . . . Sir Charles Lyell well remarks that the pure calcareous mud produced by the decomposition of the shelly coverings of mollusca and zoophytes would be much lighter than argillaceous or arenaceous mud, and being thus transported to greater distances, would be completely separated from all impurities . . . Mr. J. Murray . . . says . . . 'The Globigerina-oozes which we get in shallow water resemble the chalk much more than those in deeper water.' Mr. Gwyn-Jeffries, one of our greatest authorities on shells, taking the whole series of genera which are found in the chalk formations, seventy-one in number, declares that they are all comparatively shallow-water forms, many living at depths not exceeding 40-50 fathoms, while some are confined to still shallower waters."

Wallace discusses the occurrences of the chalk in the two great areas, from Antrim to Crimea, and from Sweden to Bordeaux, and says it is absurd to suppose that these areas were oceanic abysses, since we have good evidence for believing there was land in Germany and in several of the nearby regions. Moreover, the frequent intercalations of sandstones and conglomerates, limestones, marls, and muds, containing many of the same fossils as the chalk do not add to the abyssal theory. Finally, he says, the wide-spread emergence at the end of the Mesozoic, evidenced by unconformities which point to a Europe very similar in outline to that of today, would make it extremely unlikely that there had been any depths over Europe comparable to the present-day oceanic abysses. Wallace of course makes no mention of the modern theories of isostatic equilibrium which support his theory admirably by the doctrine of the permanency of oceanic basins. He reaches the conclusion that the chalk was a deposit laid

down under a depth of water varying from a few feet to 200 fathoms, and does not mean deep-sea conditions.

An argument favoring the warm-water origin of the chalk is the result of the work of G. H. Drew, of the Carnegie Institution, upon the precipitation of calcium carbonate from the sea-water by bacterial agencies. He says (23, p. 136), "Denitrifying bacteria possess the power of precipitating soluble calcium salts in the form of calcium carbonate from sea-water bacterial action may have formed an important part in the formation of the chalk and other limestones rocks in geologic times." These bacilli, called "*Bacterium calcis*" by Drew, grew best on or near the surface in water from 25 to 31.5 degrees C., with an average of 29 degrees; they will grow *very* slowly at 15 degrees C.; "but its growth is totally inhibited at 10 degrees C." As such temperature can only be attained in tropical and sub-tropical oceans today, it is certain that the seas of the chalk must have been of at least this warmth, if any of the chalk is due to bacterial precipitation,—a view now very widely held.

Cayeux (16, p. 258-9), says, referring to the chalk of the Paris Basin, "*La craie du Nord est bien un dépôt terrigène.*" A. Geikie agrees that it is a shallow water deposit. De Laparent still inclines to the belief that it is a fairly deep-sea accumulation. Schuchert (17, p. 885), says the evidence that chalk is a shallow water deposit is, (1) the kinds of fossils indicate shallow water, (2) the formations are accompanied by sands, (3) in closely adjoining areas equivalent strata contain no chalk. He sums the question up as follows: "It is now held that the chalks are organic accumulations made in the main by the calcareous skeletons of minute pelagic or bottom-living plants and animals, in clear-water epeiric or shelf seas, adjacent to low lands with mild climates."

The most important feature of this summary is the clear-water condition postulated. Recent work on the Selma Chalk has shown it to be a deposit laid down in water into which no muds or large amounts of sand were carried. The calcium carbonate, freed of all other sediments, accumulated in a com-

paratively shallow basin, very often not more than 25 fathoms in depth. So with the great European chalk deposits. Their purity is due rather to clear, shallow-water conditions,—conditions which a flat, peneplained adjoining land-mass would afford,—than to the clearness of abyssal oceanic waters. The depth, or the distance from shore at which these conditions would prevail, would be a function of the height of the land, strength and direction of currents, mouths of rivers, etc. This would suggest about the limit of the continental shelf, under conditions as they exist today, but in the Cretaceous it is probable that these existed at much shallower depths, for the reasons given.

In the case of the glauconitic facies of the American horizons, considerably more difficulty is experienced in reaching a definite idea as to the conditions of deposition, due to the lack of knowledge on the formation of glauconite. There has been no controversy comparable to that over the chalk. The consensus of opinion seems to place the areas over which deposition is going on today at about the edge of the continental shelf, or at slightly shallower depths. Goldman (4, p. 176-82), has a discussion of the glauconite of the Monmouth formation of Maryland, but does not state at what depth it was formed, although he says it is found at 91 meters in the North Atlantic today (4, p. 176). Sir John Murray says the glauconite, which is usually found in shells of Foraminifera when primary, is always associated with terrigenous material. The admirable work of L. Cayeux (14), discusses rather the method of formation of the mineral glauconite than the physical conditions under which it was deposited.

F. W. Clarke (18, p. 135), summarizes these as follows:—glauconite “is widely disseminated upon the sea-bottom, but most abundantly in comparatively shallow waters, and near the mud-line surrounding continental shores,” that is, “just beyond the limits of wave and current action, or in other words where the fine muddy particles commence to make up a considerable portion of the deposits.” This is usually placed at or about the edge of the continental shelf, or from 80 to 100

fathoms. Fine particles of mud are, of course, as good indications of clear water as chalk. There seems to be a general unanimity that quiet water is a requisite in the deposition of the glauconite. Goldman (4, p. 178), in speaking of the chemical reactions supposed to take place in the formation of glauconite says, "but whatever the process, the fact may be accepted that in the presence of abundant organic matter *in fairly quiet waters*, FeS_2 is formed." De Lapparent (19, p. 365), says it is deposited in "green muds which form in depths from 200 to 1300 meters along abrupt coasts, where no important rivers empty as is the case along the south coast of Africa and the coast of Australia." Grabau (20), says the glauconite is formed in shallow water, on the continental shelf, and is usually found as replacements in the fine marine muds. Chamberlin and Salisbury (21, p. 366-68, Vol. 1), remark that "Glauconite is, on the whole, most abundant along the edges of the continental shelves, though it is by no means universal in this position. It is not commonly found in deep water, nor very near the shore, but approximately at the mud line."

But where clear, quiet waters prevail for any time, glauconite can be deposited, even if the waters are very shallow. Thoulet has found it in the Gulf of Lyons from water of only a few feet. Professor E. W. Berry informs me that he has found glauconite in very near-shore deposits in the eastern Gulf region of the United States. It seems probable, in view of the predominance of sands, that the Cretaceous glauconite was formed at shallower depths than that being formed today near the edge of the continental shelf.

We are not concerned here with any of the discussions of the chemical origin of glauconite. It may be formed after the consolidation of rocks, as Cayeux has shown, and it may not be due in any way to organic agencies. All we are interested in is that the primary glauconite of the "greensands" was deposited, in quiet waters, predominantly clear, sometimes of very shallow depth, sometimes in depths of several hundred feet.

It will readily be observed that such a conclusion is identical with that regarding the conditions under which the chalk is thought to have been laid down,—warm, clear, quiet waters, from 50 to 2000 feet deep, the depth varying with the attitude of the adjacent land masses, currents, etc. The glauconitic and the chalky facies of the Upper Cretaceous may be taken, with a considerable degree of certainty, to indicate practically identical conditions of deposition,—conditions which, in view of the comparative rarity of wide-spread similar deposits before and since, were produced by a rather exceptional combination of physical factors. In such surroundings *B. americana* and *B. mucronata* appeared and rapidly became extremely numerous. Everywhere in the Atlantic province they are found flourishing while warm, quiet, clear waters prevailed. But they rarely strayed far beyond the limits of these surroundings, and where they did they quickly died out. Finally, the physical changes which brought the Monmouth and Maestrichtian to a close, in destroying the limited conditions under which the forms could live, caused their complete extinction.

Nothing dogmatic can be postulated from the study of the habitat of only one or two species. Before any universal conclusions can legitimately be drawn a very large number of forms must be studied with extreme detail and exactness. The forms I have used may be exceptional in their limitations, and therefore possibly not typical examples of guide fossils. But the evidence afforded by the occurrence of *Belemnitella americana* and *Belemnitella mucronata* undoubtedly points to the conclusion that the wide-spread occurrence of identical forms,—which thus constitute intercontinental guide fossils,—may be due to the wide-spread occurrence of identical life conditions, rather than to an especially hardy, or easily and rapidly adaptable form.

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CONTRIBUTIONS TO
PLANT PHYSIOLOGY

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THE DEPARTMENT OF PLANT PHYSIOLOGY

By BURTON E. LIVINGSTON

The Department of Plant Physiology, established in the autumn of 1909, has experienced a very satisfactory growth during the seven and one-half years of its existence. It entered the present Laboratory of Plant Physiology as soon as the building was completed, in the winter of 1911-12. The laboratory building has been described, with photographs and plans, in the *Johns Hopkins University Circular* for December, 1916. The present paper is offered as a preface to the following preliminary reports of plant physiological work now in progress or recently completed, and deals with two topics, the general aims of the department and the nature of the work so far accomplished or in progress.

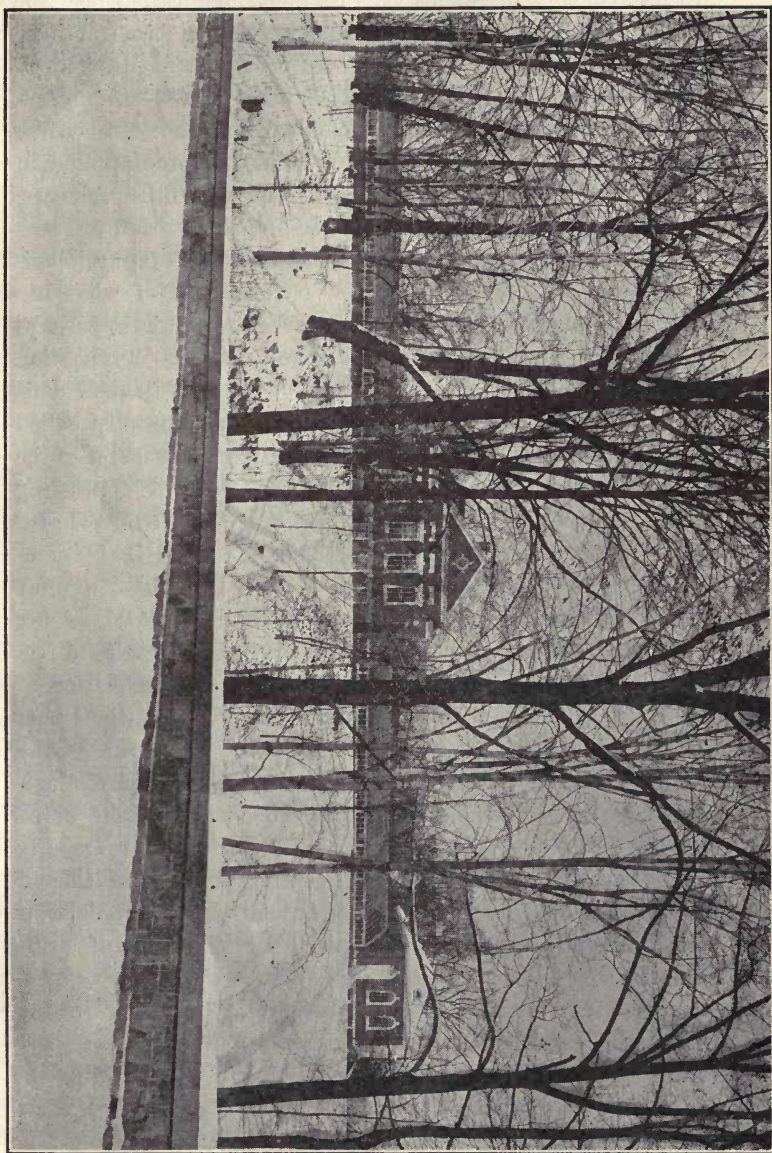
AIMS OF THE DEPARTMENT

Nature of the Science—Plant physiology occupies a somewhat uncommon position among the natural sciences, having many of the characteristics of a young science, although it is not really such. Notwithstanding the fact that people have been interested in the physiology of plants for many generations, the subject has hardly yet become generally regarded as a separate science, and it has usually been included under the general designation of botany. Animal physiology, which is, of course, the corresponding subdivision of zoology, has long been considered as distinct. The simplest way to make the content of plant physiology clear to one not acquainted with it is to point out that it deals with plants in exactly the same way as animal physiology deals with animals. Thus it has to do with all the processes that go on in plants, and it considers these processes just as physics and chemistry con-

sider the processes that go on in inanimate things. Indeed, the close relation between the physiology of animals and that of plants is becoming so well appreciated in recent years that a science of *general physiology* (dealing with the physics and chemistry of all living things) appears to be rapidly developing. It is seldom possible to treat any physiological topic adequately without reference to both plants and animals. Some of the topics dealt with in plant physiology may be mentioned as examples. Such are: water requirement; nutrition by inorganic materials; nutrition by organic materials; the exchange of energy between the organism and its surroundings; the chlorophyll function; respiration, with and without free oxygen; enzymes, activators, hormones, and the general phenomena of catalysis; the control of growth and development, including reproduction; the physiology of movement and its control, and the physics and chemistry of protoplasm.

The non-physiological aspects of biology may be grouped together as *morphology*, which deals with the structures of organisms. Perhaps one of the most noticeable aspects of physiological endeavor, and one in which it differs remarkably from morphological study at the present time, is this, that it has little to do with the general problem of evolution and phylogeny. Evolutionary philosophy has been built up largely from morphological observations, and it is only recently that it has become possible to relate different organisms to each other with reference to their physical and chemical processes. The evolution of animals and plants has never yet been one of the main topics of physiology.

The sciences of mycology, bacteriology, pathology, ecology, etc., all have their morphological and physiological aspects, and their subject-matter may be treated from the standpoint of static description or from that of process dynamics. Thus, that branch of pathology which deals with the identification of parasitic organisms is mainly morphological in its point of view, while the sciences of toxicology and immunology are clearly branches of physiology. It is not without significance that many of the characters by which the bacteria



LABORATORY OF PLANT PHYSIOLOGY (CENTER), EXPERIMENT GREENHOUSE (LEFT),
AND PART OF BOTANICAL LABORATORY AND GREENHOUSE (RIGHT).

are classified and identified are physiological, since the processes induced by these minute organisms happen to be more easily observed than are their structural differences.

Application of Physiological Science—Just as physics, chemistry, climatology and biological morphology become applied in physiology, so does physiology become applied in many other lines of human activity. As with other sciences, there are, in general, two groups of applications that are possible. First, there is the general application of physiological knowledge and principle to the formation of what has been called a “philosophy of the universe.” This is perhaps its application as “pure science,” and for this application plant physiology is almost, if not quite, as valuable as is animal physiology. Such application is not usually called an application at all, not being primarily practical for the physical aspects of human life, in the sense of “buttering bread.” But there are still men who do not live by bread alone, and a commercial age has not yet proved that a general appreciation of the relations of the things about us may not be ultimately as valuable to the human world as are those things which money buys directly. It is in this direction of application that modern natural science claims at least an equality with philology, history and the other humanities.

The second group of applications possible for physiological science includes those commonly called practical, by which food and clothing and dwellings may become more readily available to human beings, and by which human health and comfort may be enhanced. Just as animal physiology finds its most numerous applications of this sort in the fields of medicine, surgery, hygiene, animal husbandry, etc., so plant physiology contributes most to human physical welfare in the fields of agriculture, forestry, fermentation operations, bacteriology, etc. These applications are more interesting to more persons than are those of the first group and their importance is not to be minimized. Indeed, the more a science may be practically applicable the more opportunity it may have for becoming philosophically applicable. The two

kinds of application advance hand in hand, but the great majority of individuals may remain generally careless of the philosophical kind. For the growth of plant physiology and for its best service to the world, it is clear that most of its devotees must give much attention to the practical problems of plant production and plant culture, and such is indeed the case.

Both groups of applications have their philanthropic or altruistic and their personal or selfish aspects, using these adjectives in their usual sense. Thus, a world philosophy may be cultivated with the conscious aim of advancing human development in general, or with the aim of advancing certain individuals, groups or institutions, as by increased financial income. Of course, the two aspects overlap, but the broadly philanthropic aim seems to have been frequently more evident than the other among the great philosophers and religionists of the past. We are not told that a Buddha or a Christ or a Pasteur has given much attention to personal financial income or to the copyrighting or patenting of his ideas. Nevertheless, it is quite possible for a modern philosophical scientist to give attention to such personal things without detracting from the broader value of his work.

The practical applications of a science such as plant physiology may be carried forward for either altruistic or personal ends. The latter kind of activity is commonly called commercial. A plant physiologist may work for years in perfecting methods for the production of better or more abundant agricultural crops, and his main aim may be either to lower the cost of food to the multitude, or to gain for himself fame or financial profit. The work itself may be the same in both cases, and even the publication of his results and conclusions may not be markedly different. However, as in all such personal activities, the results eventually become free to the world, and may thus become just as important in general human advancement as though the work had been planned with that end in view. Personal interest can usually withhold results of this kind for only a limited time; patents and copy-

rights run their courses and commercial secrets are sooner or later divulged. As has been remarked above, the two points of view overlap, an individual's motives are seldom or never exclusively of the one or of the other kind, and they shift from time to time.

It has seemed desirable to give space to the discussion just presented, on account of the long-standing misapprehension that still exists between the exponents of "pure science" and those of the arts and commercial applications of science. The writer is convinced that all these various human motives for scientific work must exist side by side, even in the same individual, and that it is for a university department to present all of them to its students. But the outstanding fact seems to be that the work itself should be much the same in all cases, assuming of course, that actual dishonesty is ultimately as bad from the commercial point of view as it is from the altruistic, as bad in practical applications to human physical needs as it is in philosophical applications to what have been called human spiritual needs.

Training of Physiological Students—It should be appreciated that physiology articulates intimately both with biological morphology and with the physical sciences. It is obvious enough that the processes and reactions of living things are not to be understood without a certain amount of morphological or anatomical knowledge. Thus, anatomy and histology are, in this way at least, and otherwise to some extent, prerequisite to the study of physiology.

On the other hand, the changes of matter and energy that go on in living things cannot be seriously studied without a broad and rather detailed knowledge of the principles according to which such changes occur in dead matter. In this way the field of physiology furnishes opportunity for the application of physics and chemistry in the understanding of life. So important is this consideration that physiology may be defined as the physics and chemistry of living things. This consideration has not been so generally appreciated as seems desirable, and many of the present leaders in physiology have

first approached the subject through the avenues of morphological study. Perhaps it is because of this that beginners are often led to devote several years to academic work in morphological pursuits before they are allowed to become acquainted with the physiological aspect of biology, so that they discover the need of an intimate knowledge of physics and chemistry only at a rather late stage in their development. It is a significant fact that very few of the present workers in plant physiology have been led to their interest in the subject from an introductory study of the physical sciences, although physiology offers some of the most important physical and chemical problems.

Considering the general applicability of physical as well as morphological knowledge to physiological study, it is becoming more and more evident that a tyro in physiology should be encouraged to devote much more attention to physics and chemistry, in the earlier years of his preparation, than is now generally the case—which necessarily means that he should not be encouraged to devote so much time to biological morphology as he does in most institutions where young natural scientists receive their training.

The considerations just set forth have been given prominence in planning the training leading to the doctorate from this department, and, while no formal prerequisites are stated, the need of as much knowledge of chemistry and physics as the student can obtain is constantly emphasized. At the same time he is urged to become well acquainted with the main facts and general principles of animal physiology and with those of the comparative anatomy and histology of plants, as thus far available. Since climatic conditions exert such controlling influences upon the behavior of plants, that physical branch which is termed climatology must also receive much emphasis.

It is the general plan of the department to erect no artificial barriers before the prospective student; the work is so organized that any person who understands elementary phys-

ics and chemistry can enter our physiological work. If his morphological or physical knowledge is inadequate this may be corrected as his work goes on. In short, an interest in, and a serious desire to become proficient in, plant physiology are the only prerequisites for the training that is here offered.

The work of this department has thus far been exclusively *graduate* work, so that all of our students are intellectually rather mature. The scarcity of opportunities for carrying on advanced work in plant physiology, together with the fact that numerous educational institutions offer opportunity for elementary academic courses in this and the related subjects, have made it appear undesirable to institute undergraduate courses here. Experience seems to show, furthermore, that the intellectual power of graduate students is greater among those who have migrated from one institution to another, than it is among those who have performed their undergraduate work in the same institution as that in which graduate work is undertaken. Whether a causal relation is mainly involved here is questionable, for the very fact of student migration generally bespeaks a serious purpose and a definite aim; but it is also undoubtedly true that student migration tends strongly to prevent and to obliterate provincial traits of mental character, and to give to the student who has thus migrated one or more times a more extensive series of interests and a deeper appreciation of relative values.

The general purpose in the training of our students may be expressed as the inculcation of scholarly habits and of personal judgment in the carrying out of research. To this end, the work of the department is carried on as though research itself—productive scientific study—were the main aim. The student thus becomes, as it were, an apprentice in what is planned to be creative physiological endeavor, and he develops through striving to solve physiological problems and to interpret and present the results obtained. He is thus led to read the literature because he seeks the knowledge that it contains, rather than because such reading has

been assigned or prescribed. He also learns that the planning and the interpretation of experimental work require far more serious attention than does the work itself, for a poorly planned or poorly interpreted piece of work can result in but mediocre results. The actual operations of experimentation may be best learned by carrying out a well made plan, and the interpretation and presentation of the results obtained determine for the most part how valuable they shall be in the development of the science. Thus as much emphasis is placed upon clear imagination, clear thinking, and clear presentation, as upon the many details of the manipulation of apparatus, so frequently considered as constituting scientific knowledge. This department does not aim to *teach* the subject, but it carries out investigations and tries to help the workers to become independent in the planning, prosecution, and interpretation of research.

A single course of semi-formal lectures, lasting through the year, with prescribed laboratory experiments, suffices to bring the students into contact with the various phases of the subject, and instruction is thereafter mainly personal, in the form of conferences upon the numerous matters that arise in the prosecution of research. No attempt is made to standardize the students beyond the elementary phases of the subject, but each one is encouraged to develop along lines determined by its own natural bent. Consequently, problems for research are not generally "assigned," as the phrase goes in many university laboratories, but the prospective investigator is led and assisted to choose a problem according to his own earlier training and present interest and enthusiasm. An attempt is made, however, to discourage the taking up of any problem that does not promise results of a definite nature which, when they are obtained and interpreted, will surely fit into the general structure of plant physiology.

It appears probable that the majority of our students will eventually enter the field of practically applied physiology, as investigators in agricultural or forestry experiment stations, or in commercial establishments; but our point of

view is always that of the pursuit of the science for its own sake, so that as many as may be needed may find places as teachers of the subject. For all these lines of endeavor the same general kind of training appears to be requisite, as has been pointed out. Such training must aim to make the student familiar with the great principles of the science, with some of the methods employed, and with enough of the literature so that he may make efficient use of the libraries in his future work. Above all, he must be led to a facile and versatile attitude of mind, which regards his science as a continuously changing thing, with new needs arising at every turn of its progress; also, he must be not over-timid in following his problem wherever it may lead, even into the fields of other sciences.

THE WORK SO FAR ACCOMPLISHED OR IN PROGRESS

The accomplishment of a scientific research laboratory should be calculated as the sum of two different terms. The first of these is, obviously, the progress actually made in investigation, in the solving of problems, and in contributions toward what we name the general fund of human knowledge. The component parts of this term are usually easy of descriptive statement, but difficult of comparative evaluation. The second term includes what is commonly thought of in universities as the training of students, but it should also include the intellectual progress of the laboratory staff itself (which ought to accumulate to form an asset of some value) and likewise the aid and encouragement furnished by the laboratory to persons not directly connected with it at all. This term, as is readily seen, is the educational one, and its components are very difficult both of precise description and of comparative evaluation. Looked at in one way, it may be said that the first term measures the actual product of the laboratory as an institution for the *making* of knowledge, while the second measures the preparations made for the accomplishment of future work of many kinds, whether in research or

other lines of human activity. Both these kinds of effort progress side by side in the life of every individual and of every institution; each day is partly devoted to actual accomplishment and partly to preparing for future accomplishments, and the two sorts of activity cannot be clearly separated. Especially is this true when it is appreciated that the accomplishment of one worker becomes preparation for the future activities of others, as well as of the same worker. These two aspects of our work may nevertheless be considered separately.

Educational and Preparatory.—Considering the period from October, 1909, to June, 1917, 38 persons, including the two members of the staff of the department, have made use of the laboratory of plant physiology. The periods of use were: One year for 24 persons, two years for 7 persons, three years for 5 persons, four years for 1 person, and eight years for 1 person. Thus, the laboratory has furnished facilities for mental development, roughly equivalent to those for 65 persons for a single year, or for an average of 8 persons per year. Ten of the 65 academic years considered are those of the professor (8) and instructor (2).

Of the 38 individuals who have used the laboratory, four have worked here after the attainment of the doctor's degree elsewhere (two of these are on the staff), four have attained the Ph.D. degree from this university, with Plant Physiology as principal subject, and five others plan to come up for the degree in June, 1917, with this as their principal subject. Plant Physiology has been selected as a subordinate subject (in the requirement for the Ph.D. degree) by 15 persons.

Of the four persons who have received the doctor's degree from this university, with their main work in this laboratory, one is now employed in the U. S. Department of Agriculture, two in state agricultural experiment stations, and one is on the staff of the University of the Philippines. Thus, three of these have entered applied research and one is devoting a portion of his time to teaching.

The investigation carried on here has itself been largely preparatory for future work; the problems that we have desired to attack could not be undertaken until the field (which is a new one) had been specially prepared, so that our contributions to the science are to be regarded largely as beginnings and preparations. It appears likely that many of these lines of work will be carried out elsewhere, either by students of this university or by others who become interested as the field is opened. The general nature of our problems will be touched upon in the following section.

One other feature of the educational and preparatory work carried on by this department deserves mention, a feature that may be fully as important as is the direct training of students. This laboratory has furnished information and advice to many persons not directly connected with it regarding problems bearing on the water relations of plants, and has thus been able to render more or less valuable aid to students in other institutions and investigators in experiment stations, etc. To a lesser degree we have been called upon to aid outside investigators in other fields of plant physiology. It has been the practice of the department to furnish ideas and suggestions quite freely to all inquirers, a practice involving the writing of explicit and detailed letters, but one which seems to be fully as legitimate and valuable as are the consultations with our own students in residence. It is intended that no such inquiries from outside the department shall be subject to neglect or perfunctory reply; such information and suggestions as we have are furnished promptly and freely to all who ask. This makes the handling of the correspondence of the department a somewhat serious undertaking, but one that is fully worthy of the time and energy so expended. The number of persons, in many regions of the world, who are thus more or less indirectly connected with this laboratory, is much larger than the number of workers who have actually been in residence here. Also, the director of this laboratory devotes considerable time

to the editing of plant physiological papers prepared by workers in other institutions, especially for *Physiological Researches*, a series of publications with which the University has no official connection and for which it furnishes no financial assistance. An English translation of Palladin's *Plant Physiology*, with editorial additions, is about to be published from this department. It has been prepared from the German translation of the Sixth Russian edition, with incorporation of the main alterations occurring in the Seventh Russian edition.

Contributions to the Science, and Researches Now in Progress.—To give a clear idea of the nature of the investigations attempted in this department, it is desirable to present a brief discussion of the general field in which these investigations lie. The science of plant physiology deals with the processes or changes that go on in living plants. Now, to understand a change as fully as possible it is required to know the change first in a roughly descriptive sort of way, after which our knowledge is to be advanced by consideration of the dynamic and causal aspects of the process considered. Descriptive physiology involves statements of the various sorts of processes going on in the organism, and it should show in what regions of the body these changes occur, and when they occur. Thus, that ordinary green leaves take up the element carbon out of the air during periods of sunlight is a statement of descriptive physiology, in this sense. To inquire more deeply concerning this process of carbon-intake clearly leads to quantitative studies of the various rates at which this intake may go on, which may be correlated with the various concomitant conditions of the plant and of its surroundings. Such studies soon reveal the fact that the rate of carbon-absorption is determined by a host of conditions, each one of which requires to be measured with regard to its intensity, and it is found that the rate in question may assume different magnitudes as the conditional intensities vary. It is true that the process of carbon-entrance from the air usually

ceases, and is replaced by one of carbon-exit, when light is absent, but the same alteration may be induced by many other changes in the surroundings; for example, by sufficiently high or low temperature, by sufficiently low water-content of the leaves, by a sufficiently high concentration of a poisonous gas in the air, etc. It soon becomes clear that no physiological process is to be regarded as at all well understood without a considerable knowledge of its quantitative control, and dynamic physiology deals with the more elaborate and quantitative statement of the physiological changes thus suggested. It relates them to their determining conditions within and without the organism.

From the work of earlier students many plant processes are now fairly well known in the simple, descriptive way, but none of these is yet at all well understood in the dynamic or etiological sense. This latter is the phase of physiology which is now beginning to attract the most serious attention, and to it will be devoted the energies of investigators for many generations to come. It is to this field of dynamic physiology that the researches of this laboratory are planned to apply.

While descriptive physiology, as above defined, is a comparatively old science, dynamic physiology is a young one, and the problems of the latter are complicated in the extreme—there are so many different kinds of conditions that may take part in the control of plant processes, and each of these conditions may be effective with so many different intensities. The complexity and newness of these dynamic problems explain the fact that the very methods needed for the sort of study here suggested are, for the most part, still to be devised. It is obvious that dynamic physiological investigations must rest upon comparative measurements of the intensities of effective conditions and of the concomitant or resulting rates of the processes that are to be investigated, so that studies of the possible ways by which such measurements and comparisons may be made must constitute the beginnings in this field. All of our work has aimed at this causal sort of explanation of process rates,

but much of it, as so far carried out, has resulted in little more than giving us certain methods of study and certain incomplete results. The problems are so complex that broad generalizations cannot be looked for for a long time.

It has so happened that two phases of dynamic physiology have thus far occupied much of our attention, as far as research is concerned. At the same time, these two phases are among the most fundamental of all, as regards plant growth in general, and the agricultural and forestal production of plant material in particular, and they also appear to represent the very simplest problems in plant control. The first of these phases, or groups of dynamic problems, deals with the *water relations* of plants; the second deals with their *inorganic-salt relations*. The connotation of these two groups of problems may be roughly suggested to the reader by the statement that the agricultural operations of drainage and irrigation are related to plant water relations, while fertilizer practice is related to inorganic-salt relations. A large number of the contributions from this laboratory have dealt with one or the other of these general phases. The measurement and experimental control of the environmental conditions of moisture and of inorganic salts, and the relation of these conditions to plant growth, have thus received a large portion of our attention.

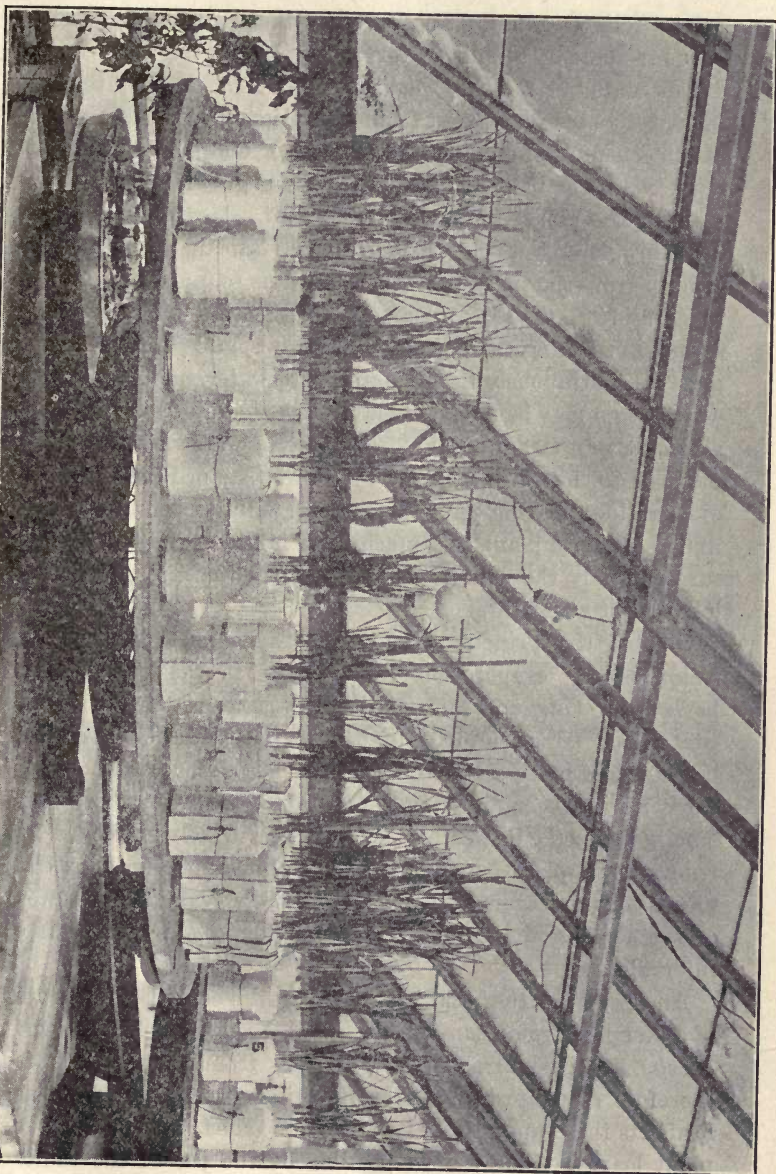
Along with the study of external conditions, the internal conditions of our experimental plants must, of course, receive consideration. While these conditions are generally much more difficult of adequate measurement than are those of the environment, some progress has nevertheless been made in this direction. For example, the work of this laboratory has aided the advance of our knowledge of the manner in which internal conditions control the rate of water-loss from plant leaves, a very important subject, both to the science of plant physiology and to the arts of agriculture and forestry.

The relations of temperature and of oxygen supply have recently begun to receive attention here, as well as the light

relation (besides its consideration as a term in the water-relation). The complex relation holding between plant growth and what is generally understood by the vague word *climate*, also enters into some of our more recent undertakings.

This is not the place to attempt a presentation of the detailed results so far obtained in the research work of the Laboratory of Plant Physiology, although it may be remarked that some apparently valuable results have already rewarded our efforts. What most requires emphasis here is, however, that a large amount of necessary preparation has been accomplished, getting ready for rational experimentation in the future. Many new methods of operation and of interpretation have been evolved, and it appears as though the time may not be remote when some of the broader aspects of the conditional control of plant activities may be undertaken with some promise of a satisfactory outcome. Such broader problems will probably have to be left to other institutions, with more facilities and larger appropriations than are now generally available for university laboratories.

To summarize the last few paragraphs, our operations have been and are directed toward a dynamic analysis of plant activity. The point of view here employed may perhaps be envisaged if the reader will regard the living plant in somewhat the same general way as he might any complex machine, such as a gasoline motor, for example. To understand its working one must understand how and how much various conditions may affect such a machine; in short, he must become an *engineer* with respect to that particular mechanism. Dynamic plant physiology may be said, then, to be engineering science as applied to the operations of the living plant. It can progress only through quantitative studies,—through experimental tests under controlled or measured conditions, through the comparison of efficiency graphs and curve-tracings made by recording instruments, through the mathematical interpretation of relations between conditions and process rates, etc.,—and it is with just this sort of studies that our investigations have to do.



INTERIOR VIEW IN ONE OF THE EXPERIMENT ROOMS OF THE LABORATORY OF PLANT PHYSIOLOGY, SHOWING A ROTATING TABLE WITH WHEAT IN WATER-CULTURE AND A WHITE SPHERICAL POROUS-CUP ATMOMETER.

The following paragraphs present the main contributions thus far made by this laboratory.

The water relation of plants.—This relation involves the plant responses that result from alterations in the supply and in the consumption or loss of water. For temperate regions it is the main conditional relation for plant growth in the open, whether the plants be wild or cultivated. Most of the water necessary for plant growth is given off into the air, by evaporation from the plant surfaces, almost as soon as the water is taken up from the soil; the amount of this liquid actually consumed in forming the plant body is very small. Active plants must be continuously impregnated with water, and the loss by evaporation may be likened to a very considerable but unavoidable *leak* in a steam engine. The rate of water supply to the plant must be great enough to counterbalance this loss by evaporation, or the growth process will be retarded. To understand the plant as a machine it is thus primarily necessary to study the conditions that control the rates of water-loss and of water-intake.

One of the principal conditions that affect the rate of water-loss by evaporation from plants is the *evaporating power of the air*, and this condition needs to be studied quantitatively. To accomplish this the porous-cup atmometer has been devised and perfected during the last decade, most of the work having been done in connection with this laboratory. The instrument, in various forms, is now widely employed by students of plant growth. The readings obtained by its means may be regarded as measures of the evaporating power of the air and they may be obtained for any desirable time intervals.

Another condition that takes part in the control of the rate of water loss from plants is the *intensity of absorbed radiant energy*, received directly or indirectly from the sun. It is therefore requisite to measure and integrate this intensity as it affects the evaporation of water from moist surfaces such as plant leaves. This is now possible by the use of the radio-

atmometer, which has also been devised and perfected here, and this apparatus is likewise coming into general use.

The two conditions just mentioned are both effective *from without the plant*; they are external conditions. There is also an internal condition (effective *from within the plant*) that exerts great influence upon the rate of evaporational water-loss from plant surfaces, and this has been called, in our discussions, the *transpiring power* of the plant. Studies largely carried out in this laboratory have resulted in the perfection of methods by which the intensity of this internal condition may be evaluated, and integrated over convenient time periods. Reference is here made to the method of relative transpiration and to that of cobalt-chloride paper. Both are now frequently employed in studies of plant growth.

As has been mentioned, the rate of water-supply to the plant also requires attention in studies of the water relations. This is primarily the *water-supplying power of the soil*, another external condition. The need for quantitative study of this has led to investigations in the realm of soil physics, and our efforts have already resulted in some useful methods of approach, but more work will be necessary before we can deal with this subterranean condition as satisfactorily as is now possible with the conditions that are effective above the soil. Out of our work has come the *auto-irrigator*, an instrument which maintains the moisture conditions of the soil nearly constant throughout long periods of time. Its readings indicate the rates at which an experimental plant removes water from a soil mass thus automatically supplied with water. The auto-irrigator is now employed by many experimenters, in cases where it is desired to maintain a constant soil-moisture content. Soil osmometers have also been employed in the study of the water-supplying power of the soil as related to absorption by plant roots.

By the employment of these various methods, all perfected here within the last few years, we have been able to begin to understand some of the more fundamental features of the

plant water relation, and the near future promises much greater advances.

The inorganic salt relation of plants.—This relation involves the plant responses that result from alterations in the supply and in the consumption or loss of inorganic salts. So far as studies of this relation have progressed, these have dealt mainly with the power of the surroundings to deliver inorganic salts (or the ions into which they dissociate) to plant roots, as this power is related to growth. This aspect of this relation has formed the subject of very many experimental investigations during the past century, but the work of this laboratory has approached the problem from a somewhat new point of view.

The soil presents such a very complicated physical and chemical system that it is quite hopeless, for the present, to attempt to understand the behavior of soil salts in any way adequate to the needs of plant physiology, and our attention has been turned exclusively to the study of plant growth in nutrient solutions and in sand cultures. For the growth of ordinary plants it requires only seven ions of inorganic salts to produce satisfactory growth, these being: potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), nitrate (NO_3), sulphate (SO_4), and phosphate (PO_4). Iron is needed in relatively but very small amount, it being only necessary that the solution bathing the plant roots shall contain a trace of this ion. Variations in the partial concentrations, or in the supply, of the other six ions may produce marked alterations in growth, however, and it is with reference to these that our work was begun. By means of elaborate series of different culture solutions the effects upon the plant, of altering the salt proportions in the nutrient medium, have been experimentally studied. It has been possible to devise a 3-salt nutrient solution for use as a standard, in which the three salts (CaNO_3 , MgSO_4 and KH_2PO_4) are present in proper proportions to produce a physiologically balanced solution, producing excellent growth. The proper salt proportions for any plant form,

and for any given complex of external conditions may readily be determined. All the various standard nutrient solutions heretofore employed have contained at least four salts (besides the trace of iron), and have been correspondingly more complex and difficult to handle and interpret. This work applies to many phases of the art of fertilizer practice, as employed in agriculture, and it furnishes a method by which we may now begin to study the salt relation as influenced by the conditions of the water relation, the temperature relation, etc.

The effects of some other inorganic ions upon plants have begun to receive attention here, also the effects of variations in the oxygen content of the soil.

The relation of plants to climatic conditions.—The main climatic conditions that affect plants are air temperature, atmospheric evaporating power, and the effective intensity of solar radiation. Other climatic conditions generally affect plants only indirectly; for example, rainfall influences the water-supplying power of the soil.

The studies thus far undertaken in this laboratory have dealt with an attempt to find out in what manner and to what degree the annual march of the complex of climatic conditions may be related to the corresponding annual or seasonal march of plant growth-rates. From these studies has been developed a method by which it appears possible to compare climates (of different places at the same time or of the same place at different times) in terms of the growth-rates of a standard plant. The plant is thus employed as an automatically weighting and integrating instrument.

This general relation is of great importance to agriculture and forestry and the point of view here taken (that of the conditional control of plant processes) is attracting the attention of investigators in these subjects. The problems are exceedingly complex, but progress is being slowly made.

The reader will be able to form a somewhat more concrete conception of what has thus far been accomplished, by reference to the list of publications from this department, which follows the present paper.

LIST OF PUBLICATIONS FROM THE LABORATORY OF PLANT PHYSIOLOGY

October, 1909, to February, 1917.

(Arranged by years, the year beginning October 1.)

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ATMOMETRIC UNITS

BY BURTON E. LIVINGSTON

The increasing interest in atmometry¹ and the fact that this subject is becoming recognized as of general and fundamental importance in many branches of scientific and practical endeavor, make it desirable that there be some uniformity in our conceptions as to the units employed in atmometric measurements. To approach the subject it is first necessary that the purpose of atmometric observations be clearly in mind; much vagueness still prevails in this connection. The rate of evaporation of water from any surface is dependent on two sets of conditions. One set (internal ones) are effective in or behind the surface and the other (external ones) are effective in front of the surface, that is, in the gas phase of the system. The internal conditions are the characteristics of the evaporating surface and include such features as the concentration of solutes in the liquid water, the influence exerted by the presence of a solid in which the water is imbibed, the shape and extent of the surface, its direction of exposure, its ability to absorb or emit radiant energy, the heat-conducting capacity of the material back of the surface, etc. The external conditions include primarily four characteristics of the space in front of the evaporating surface: the temperature of the gas phase, its moisture condition, the influence of movement or circulation of the gas over the surface, and the effective intensity of impinging radiation. I have used the term

¹ I employ the word as synonymous with and shorter than *atmidometry*, just as I have adopted *atmometer* in place of its rival, *atmidometer*. Both are etymologically correct, but the one formed from the root *atmo*, besides being shorter, has received the sanction of an international meteorological congress. *Atmometer* seems to have been coined by Sir John Leslie, 1813. (See Livingston, B. E., "Atmometry and the porous cup atmometer." *Plant World* 18: 21-30, 51-74, 95-111, 143-149. 1915. Other papers are there cited.)

evaporating power of the air to include the first three of these, since the gas phase is air in most studies and since these three features are properties of this gas. The fourth feature depends only indirectly, and to a comparatively slight degree, upon the characteristics of the gas phase next to the evaporating surface. In climatological atmometry this is the effective intensity of solar radiation, direct or indirect, which depends upon the season, the time of day and the state of the sky, as well as upon the nature of reflecting surfaces in the vicinity.

Since evaporation is a *process* and not a state of matter, its magnitude has to be expressed in terms of time rates. While temperature, for instance (being a state of matter), may be expressed in degrees on a thermometer scale, evaporation intensities must be stated as the amount of water evaporated in a unit of time. Atmospheric evaporating power refers to the external surroundings of the evaporating surface (usually to the air space above it, about it, etc.) and it need not specifically refer to the air itself, for if there were no air present this space would still possess an evaporating power. The evaporating power of the air over a surface is considered as proportional to the *reciprocal of the tendency of all the conditions effective in the space over that surface to resist the vaporization of water therefrom*.

There have been some who have objected to this expression, but they have not put forward another term. From a long-continued attempt to acquire modes of expression by which we may hope to deal with the dynamic aspect of plant and animal environments an alternative expression has developed, which may be brought forward here.

In all considerations of the dynamic relations between organisms and their surroundings we find it valuable to consider the internal and the external complexes of influential conditions separately, and each group of conditions may be expressed, for any process we may have to deal with, as a single value or *index*. We may thus speak of the index of transpiring power, the index of environmental radiation, and

the index of the evaporating power of the air. From this last expression comes the new term, the *atmometric index* of the locality and time period considered.

The *atmometric index* is the relative measure of the evaporating power of the air, and it is to be expressed as a possible time rate of doing work; it is an index of a power. The unit of measurement must therefore be a unit of work, but it may just as well be a unit of process rate, if the same process be always employed. Thus it may be stated as the amount of water evaporated per unit of time. If the liquid water were always at the same temperature this would actually be a measure of work. That the water of evaporating surfaces varies in temperature has been thus far neglected in this whole line of enquiry, the errors thus arising being relatively small in the present early stages of our studies.

To determine the numerical value of the atmometric index, we must also consider a factor representing some standard unit of surface. It has been seen above that the power of any surface to give off water vapor is determined by the characteristics of that surface, and that the *extent* of the surface is not by any means the only characteristic that needs to be considered. The shape and the direction of exposure of the surface must be taken into account, and also the influence of the non-aqueous materials that are in or behind the surface, etc. It is therefore impossible to employ a surface unit defined by area alone. As soon as this is realized all attempts to express the atmometric index as a time rate of evaporation from a square centimeter (etc.) of free water surface are seen to be quite useless. A free water surface is more or less nearly plane and more or less nearly horizontal (depending upon the wind velocity, among other things), but it may be of any shape or size, and all these characteristics are important. With a given set of aerial conditions two different atmometer pans, for instance, can give off the same amount of water per hour, per square centimeter of surface, only when they are of the same size and shape. Also, the depth of the water and

the nature of the pans themselves must be exactly alike. It is thus both theoretically and practically impossible to express the surface factor in the atmometric index by a unit that represents merely extent of surface.

Since the complex of internal conditions that make up the capacity of any surface to produce evaporation is very difficult of analysis, we may avoid the necessity of this analysis by simply using atmometer surfaces that *act alike*. Then the surface factor of our unit of measurement becomes the surface of our instrument (with whatever characteristics it may have), and we do not need to enquire what may be its area, etc. In all the studies so far carried out with porous clay and paper surfaces for measuring the evaporating power of the air, I have never been led to determine the area of the surface employed; it would have been useless to do so, although such a surface is easily measured. We are thus led to the proposition that the atmometric index is to be expressed in terms of (1) a weight unit of water, (2) a time unit, and (3) a given standard instrument. All these desiderata are supplied in such a statement as this: that the evaporating power of the air in a given locality and for a given period is such as to produce the evaporation of so and so many grams of water per hour from a standard spherical porous-cup atmometer. No unit of area is considered, although all the internal characteristics of the instrument are implied by its name.

It is clear that it makes no difference what sort of surface we may use as standard, but we must use the same standard throughout any series of comparative measurements, and when several instruments are needed we must be sure that their internal characteristics are as nearly alike as possible, as far as these characteristics may influence the rate of evaporation. The only feasible way to compare a number of instruments in this last regard is to place them all in the same environment (as far as environmental characteristics may influence the rate of evaporation) and then compare their evaporation rates. If these rates differ this must be because of internal

differences in the instruments. That two porous cups or pans of water are of the same size, shape, color, etc., does not necessarily indicate that they may be expected to give like readings if placed in the same environment, for other, less easily recognized characteristics of the instruments may not be without influence, and the surfaces may differ with respect to some of these. This consideration leads to standardization and the use of a rotating table.

By this procedure an index is obtained that represents relative capacity of each of the instruments tested, to give off water vapor, and the index of each one is expressed as a coefficient of correction, a number by which the readings of that instrument are to be multiplied in order to give the reading that would have been obtained from the master standard instrument if it had been operated for the same time and at the same place. If an instrument is effectively just like the master standard its coefficient is unity. It is not possible, however, to obtain useful coefficients for instruments that differ appreciably from the standard in form, size, etc.

Since it is necessary that several instruments be practically alike if their readings are to be comparable, it is highly desirable that different workers use as few different forms of instrument as possible. For studies on the details of the evaporation process itself various kinds of surfaces are desirable, but for general climatic atmometry the number of kinds should be kept as small as may be. This seems to be not at all well understood, and workers who have not taken the trouble to appreciate just what is the purpose of atmometric measurements continue to construct new types of instruments and to employ them. For example, the idea is abroad that if the right sort of instrument might be devised its readings would indicate relative rates of plant transpiration. Obviously such an instrument would have to alter its internal conditions from minute to minute, just as would occur in the standard plant individual, and all other plants would usually differ from it. The idea is bootless. We do not wish to measure plant tran-

spiration but to measure the atmometric index of the air in terms of its effect upon a standard instrument whose internal conditions do not change. The internal conditions of each plant or group of plants must be studied in relation to the unchanging ones of the instrument. A given temperature change does not affect all objects or processes alike, yet we do not construct a new thermometer scale for each object or process with which we deal. It may be well to mention in this connection that atmometry should furnish climatological data applicable to many fields of endeavor; the animal ecologist requires these data as much as does the plant ecologist, and irrigation engineers and students of atmospheric hygiene and ventilation all have use for atmometric measurements.

In choosing the instrument to be used the first condition to be met is that its internal conditions or characteristics should not alter; they should be uninfluenced by changes in the surroundings, for it is changes in the latter that we wish to measure. This requirement immediately excludes all forms of free water surfaces, since they alter with wind, etc. Nevertheless, since an open pan of water is the form of atmometer employed by the U. S. Weather Bureau, since this is the simplest form of instrument that is useful in any way, and since data obtained with this pan will surely prove of much greater value than no atmometric data at all, the pan of water must be accepted as the crudest and most imperfect form of atmometer. It should be added that if pans of water are used they should generally be of the same form, size, etc., as the standard recently adopted by the U. S. Weather Bureau. If this be adhered to, all pan measurements will be comparable among themselves and with the Weather Bureau data, as far as this is possible with that general class of instruments.

The second requirement for an evaporating surface is that it should be as sensitive to all the effective conditions of the surroundings as is possible, without any alteration in its internal characteristics. It should therefore be a surface that is freely exposed to wind action. A nearly ideal surface would

be that of a small, spherical droplet of water suspended freely in the air. This is not practicable, but the Livingston standard spherical porous cup seems to approach this desideratum as nearly as is possible when general ease of manipulation is considered. Since we have been able to obtain these porcelain spheres I have regarded the quest for a practically perfect surface as at an end. Some form of imbibed porous surface is undoubtedly best for general purposes, and students of ecology, ventilation engineers, agriculturists, etc., should avoid the free water surface if possible, unless it is desired that the results obtained be roughly comparable with those obtained by the Weather Bureau.

A third requirement is not as important now as it will be later, after more atmometric data have been collected. This is, that the instrument should be like some form previously used, so as to give data that may be comparable with at least some of those already on record.

Of the different forms of imbibed porous surface there are four that should be more or less generally useful: the Piche paper disk, the Bellani porous clay disk, the Babinet cylinder and the Leslie sphere, the last three having been recently improved in our own work. Probably more measurements have been made with the Piche paper disk and with the Livingston standard cylinder than with any other types of instrument, but the Piche instrument has serious practical shortcomings and the sphere is more nearly perfect than the cylinder. The cylinder will remain an important instrument for a long time but the sphere will almost surely replace it eventually. A fourth feature of the porous sphere may be emphasized as desirable, namely, the ready applicability of this type of instrument to the measurement of effective radiation intensity, which is the other aerial condition of evaporation besides the evaporating power of the air. Since we have been able to obtain black porous spheres of the same size as the white ones, the spherical form has become almost essential in all work in atmometry involving radiation. The two spheres, one white

and one black, when operated together, make up the radio-atmometer, for use in studies of radiation as an atmometric condition.

Whatever type of evaporating surface is employed, this surface must be clearly defined, so that the data obtained will not, by any chance, be regarded as comparable with other data derived from another type of surface. This means that the essentials of the instrument must be described, but this can be accomplished by merely naming the instrument and referring to some previous description. Thus, it may be stated that a given set of data were obtained by means of the U. S. Weather Bureau pan, the Briggs and Shantz shallow pan, the Livingston standard sphere, etc. If a new type of instrument has to be used it requires a complete description.

In stating the amount of water lost from the given instruments during a unit of time, it is of course unimportant what water unit is employed, so long as it is definite enough for the work in hand. Since the whole aim of atmometry is to measure a power to do work, and since the amount of liquid water vaporized per unit of time is considered as a measure of this power, weight units rather than volume units should be used. Nevertheless, if the temperature does not vary too much, from reading to reading, and generally if there is no need for extreme precision, volume units may be used, and we may consider that a cubic centimeter of water weighs a gram.

Obviously, the volume or weight of water lost from a certain type of instrument for a unit of time may always be multiplied by any value that the worker may like, so long as this value is stated, and so long as it is always applied to all readings from this same type of instrument. This treatment does not alter the relative values of a series of comparable readings and the results remain comparable. This principle makes it logical to use depth units instead of volume units, for free water surfaces, for the depth of water lost from a given cylindrical pan is the volume lost, multiplied by the reciprocal of the surface area, this coefficient being a constant for the instrument.

With open pans it is easier to measure depth than volume, for rough approximations. It is true that volume or weight readings from other types of instrument than those employing an open pan, may also be multiplied by a constant throughout the series, and this constant might be the area of the surface employed, or any other number that may be chosen. But it cannot be too strongly emphasized that such treatment is to be applied only to series of readings that are already comparable, and that no constants can be found by which readings from different types of instruments may be rendered comparable.

The use of depth units in comparing water losses from open pans has introduced and supported a fallacy that is extremely hard to combat in the minds of those who have not given the subject of atmometry serious attention. This fallacy is based upon the mistaken idea that the area of the evaporating surface is the only surface characteristic that can influence the rate of evaporation. If different sizes of pans are employed the readings are incomparable, and they remain incomparable even after each one has been divided by the area of its own water surface. Readings must be stated as from a *certain instrument*, in any event, and the application of an areal coefficient only complicates matters. To avoid the continuation of this fallacy, as much as may be, it is highly desirable that all atmometric readings be stated in terms of weight or volume, even though they were originally obtained by measurements of depth.

The worst feature of the use of depth units in pan atmometry is that it has led to another fallacy, by which these depth units are taken to be equivalent to the other depth units that are employed in the measurement of rainfall. The two classes of units look alike but they are widely different in their meanings. An example may illustrate this very important point. Suppose that the rainfall for a certain place is found to be 75 cm. (of depth) for a certain year, and suppose that the observer states that the evaporation from a Weather Bureau pan for the same period was 90 cm. (also of depth). In such a case students of climatology have been led to say that evapo-

ration exceeds precipitation by a certain depth, 15 cm. in this example. But this means nothing at all; if the pan used had been larger or smaller, of different shape or material, or if a wet soil surface had been employed, etc., the result would have been quite different, and the climatic conditions would surely not have been altered by merely changing the atmometer. On the other hand, if any other form or size of raingage had been employed the results would be sensibly the same. The amount of evaporation depends largely upon the atmometer but the amount of rainfall recorded is practically independent of the raingage, so long as the latter is a raingage at all. It is legitimate to state the index of rainfall in depth units, for this is not seriously influenced by the internal characteristics of the gage, a statement that cannot be made of the index of evaporation, nor even of the index of atmospheric evaporating power. The only logical way by which atmometric and precipitation measurements may be compared is by means of their *ratio*, in which case one set of measurements may be in depth units and the other in volume or weight units. They are not commensurable in any case, so it is best not to have them even appear as though they were commensurable. Other considerations, into which I cannot go in this place, lead unequivocally to the same conclusion.

Fortunately, there is no serious difficulty encountered in the statement of the time feature of atmometric measurements. For short periods the hour is most convenient, for longer periods the day, week and year are all suitable. Since months vary in length, monthly atmometric indices are unsatisfactory. After the three features of the unit to be used have been decided upon, it is necessary to remember that atmometric measurements, like other power measurements, always apply to a certain set of circumstances and to a certain time period. The set of circumstances here emphasized is the surroundings of the atmometer, they comprise the various features of its *exposure*. The readings refer to the evaporating power of the air only for the particular location in which the instrument was operated. The evaporating power of the

air may be very different in two locations only a few centimeters apart. The differences here encountered are much greater than the similar ones met with in thermometry and the general exposure of the instrument needs to be stated in all climatological studies of atmometry. The readings obtained are taken as averages for the time period of operation and are stated with reference to a shorter time unit.

To summarize the points brought out above, every atmometric measurement should be formulated so as to include all the five features indicated by letters in the following statement, which is given as an illustration. The atmometric index for location *A*, for the period of operation *B*, is found to be *C* units of water lost per time unit *D* from an atmometer of type *E*. Filling in the features represented by these letters, to render the illustration more concrete, we may say: The atmometric index for a place 1 meter above the ground in the center of a large field of clover in northern Ohio, for the period of operation from May 1 to May 10, 1916, was found to be 12 grams of water lost per day from a standard white spherical atmometer. If any of these five features is omitted from the statement, the meaning is rendered vague and uncertain.

THE VAPOR TENSION DEFICIT AS AN INDEX OF THE MOISTURE CONDITION OF THE AIR

By BURTON E. LIVINGSTON

Studies on the manner in which external conditions control the activities of animals and plants must deal with the moisture conditions of the air in all cases where the organisms considered are aerially exposed. While atmospheric evaporating power (measured with reference to some standard evaporating surface) furnishes an index of the air conditions that influence the rate of water loss from aerially exposed organisms, it is frequently desirable to analyze this complex

condition into its two components, the moisture condition of the air and the velocity of air movement or circulation. For such an analysis atmometric observations are of course inadequate. Furthermore, it is often requisite to compare different evaporating powers of the air when the air movement is known to be constant, in which case the moisture condition is the only variable to be taken into account. Finally, in the artificial control of the air conditions of culture chambers, the rooms of dwellings, etc., it is frequently possible to maintain air circulation without much fluctuation and then to control the evaporating power by controlling the moisture condition. In such cases it becomes important that serious attention be given to the moisture condition of the air and its adequate measurement.

By *moisture condition* is here meant *that factor in atmospheric evaporating power that is independent of the rate of air movement*. It is thus an index of a condition determined by the state of saturation of the air (with aqueous vapor) and by the air temperature. Humidity, as commonly measured, does not involve temperature. To make these relations clearer, it may be added that the index of atmospheric evaporating power should be equal to the product of the index of the moisture condition and the index of circulation: $I_e = I_m \times I_c$. Of course it is here assumed that all measurements of conditions have been properly weighted and brought into correspondence, in deriving the indices. Otherwise a coefficient of proportionality needs to be applied to each of the quantities. In this equation, the value I_m is the one with which this discussion deals.

The tendency of water to evaporate into air lying next to the water surface is measured by the maximum vapor pressure possible with the prevailing conditions of the surface. If pure water is considered the maximum value may be obtained for any given temperature, from published physical tables. It will be lower than these published values if the water is impure, or if it is held by imbibing solids, etc. It is a gas pres-

sure, and is expressed in pressure units, as the height of a mercury column, fractions of an atmosphere, etc. It may be considered as equal to the pressure that drives the water vapor out of the liquid surface, which may be termed the *vaporization pressure*. The temperature of the liquid lying close to the surface exerts a marked influence upon the magnitude of this pressure.

This tendency for water to evaporate is opposed by another tendency, that of the air to deposit liquid water on the evaporating surface; it is the tendency of water vapor to condense. This is measured by the partial pressure of water vapor in the air lying next to the evaporating surface, and it may have any value between zero and the maximum vapor pressure of water vapor for the given air temperature. It also is a gas pressure and is measured in pressure units. The most satisfactory method of measuring it is by means of the Regnault dew-point apparatus, through determining the temperature of the dew-point, the partial pressure of water vapor in the air being equivalent to the maximum vapor pressure of liquid water at the temperature of the dew-point of the air. Another less satisfactory method of determining this partial pressure is by means of the sling psychrometer, the readings being interpreted by physical tables published for this purpose. This actual partial pressure of water vapor in the air may be termed the *condensation pressure*.

From this it follows that the difference between the vaporization pressure and the condensation pressure must determine the value of that factor of atmospheric evaporating power that is not determined by air circulation. This difference is the vapor pressure deficit, measured as a pressure; it is the excess of vaporization pressure over condensation pressure. For most purposes of approximation it may be supposed that the temperature of the liquid surface and that of the general air are the same, but this is not strictly true, and the temperature value employed in deriving the vaporization pressure ought really to be measured just within the liquid,

if the evaporating power of the air for any particular surface is to be studied. The condensation pressure should be determined for the general atmosphere of the space under consideration. If air circulation were infinitely rapid, which means, practically, if there is a high wind, this deficit value should be a measure of the evaporating power for the particular location considered. Also, if two sets of conditions are to be compared, in which the air circulation is the same, then the two atmospheric evaporating powers should be proportional to the corresponding vapor pressure deficits; for the other factor is then common to both sets.

To illustrate the use of the vapor pressure deficit, let it be supposed that there are two rooms in which the air circulation is alike, and let it be required to estimate the relative values of the evaporating powers corresponding to the two rooms. The data involved and the results obtained are shown below, together with the two relative humidity values, as usually given in such comparisons.

	Air tem- perature	VAPOR PRESSURE		Vapor pres- sure deficit	Relative humidity
	deg. c.	Maximum mm. of Hg.	Actual mm. of Hg.	mm. of Hg.	per cent.
Room 1.	20°	17.41	14.50	2.91	83
Room 2.	25°	23.55	6.14	17.41	26

The values used in this example have been so chosen that the deficit for Room 2 is 17.41 mm., just what it would be for Room 1 if the actual vapor pressure were taken as zero. This is the maximum deficit for a temperature of 20°. Nevertheless, it is seen that the actual vapor pressure for Room 2 is far from zero. This emphasizes the point that the maximum evaporating power of the air increases with the temperature, air pressure, and circulation remaining the same.

Such comparisons have usually been made in terms of *relative humidity*, the values for which are presented in the last column of the tabular arrangement just given. This mathematical abstraction is the *ratio* of the actual to the maximum

vapor pressure of water vapor in the air, while the vapor pressure deficit is the *difference* between these two vapor pressures. Relative humidity percentages are without value unless the air temperature is also given, whereas the deficit values need no reference to air temperature for their interpretation.¹ The fallacy in the employment of relative humidity clearly lies in the fact that its values are ratios and that the denominator of the ratio varies with air temperature; different percentage values cannot be comparable unless they are calculated to the same base.

In the illustration given above, the relative humidity index for room 1 is 3.25 times as great as that for room 2, and the popular conception of relative humidity might lead to the erroneous supposition that the evaporating power of the air for room 2 should be 3.25 times as great as that for room 1, whereas this last number should be the value of the fraction

$$\frac{17.41}{2.91} \text{ or } 5.98.$$

The real uselessness of the concept of relative humidity and the manner in which this concept is frequently misleading are brought out by the fact that the index of relative humidity may be identical for two rooms or for two climatic stations, and (owing to a difference in air temperature) the moisture factor of the evaporating power of the air may be very different in the two cases. Thus, a relative humidity of 60 per cent. corresponds to an air moisture factor of 10.44 mm. at 20°, and to one of 14.13 mm. at 25°. The moisture condition of the air in the second case is much higher, but the relative humidity values fail to suggest any difference.

One of the most serious reasons for discontinuing the use of relative humidity lies in the fact that the moisture condition of the air generally varies from hour to hour and from

¹ For some very true remarks in this connection, see: Stevens, Neil E., "A method for studying the humidity relations of fungi in culture." *Phytopathology* 6: 428-432. 1916. Other references are there given.

day to day, for the same place, which makes it necessary in climatic discussions to resort to averages and means. While the index of relative humidity for any instant may be readily interpreted by use of the corresponding air temperature, there is no possible way by which an average of several such indices may be so interpreted; the average temperature for the period is of no use for this purpose, since the march of temperature for the period is not necessarily at all related to that of the moisture condition. The only way to give definite meaning to a relative humidity mean is to obtain the original humidity values from which the mean was derived (together with the corresponding air temperatures), to substitute for each individual value the corresponding vapor pressure deficit, and to derive the mean of the deficits, thus discarding relative humidity altogether.

For biological experimentation, for hygienic studies of the air moisture condition in dwellings, and for general climatological purposes, it is very obvious that the whole concept of relative humidity is hopelessly misleading; the sooner this concept can be forgotten the more rapidly will knowledge advance. When it is not desirable or expedient to employ the index of atmospheric evaporating power itself (as determined directly by some form of atmometer), the moisture condition of the air should be stated in terms of the vapor pressure deficit, which demands no correction for air temperature and may represent evaporating power in all comparisons where the index of effective air circulation may be considered as constant.

INCIPIENT DRYING AND TEMPORARY AND PERMANENT WILTING OF PLANTS, AS RELATED TO EXTERNAL AND INTERNAL CONDITIONS

By BURTON E. LIVINGSTON

It has been shown by Renner,¹ by Livingston and Brown,² by Lloyd³ and by Edith B. Shreve,⁴ that the water content of plant leaves, twigs, etc., is markedly lower after a period of relatively great transpiration (as in the middle of the day) than it is after a period of very small transpiration (as in the latter part of the night). The moisture content of leaves, for instance, was found (Livingston and Brown) to exhibit a diurnal march, the rate of water loss from these organs during the forenoon hours (or even during the whole period of sunshine) being greater than their rate of water intake, while the rate of foliar intake of water during the night hours was greater than the rate of water loss. The phenomenon indicated by diminished water content in the daytime was called *incipient drying* by Livingston and Brown. Renner employed the term *sättigungsdefizit* to denote the similar phenomenon encountered in his experiments. The experimentation of all but Renner, of the authors mentioned

¹ Renner, O., "Experimentelle Beiträge zur Kenntnis der Wasserbewegung." *Flora* 103: 171-247. 1911. *Idem.*, "Versuche zur Mechanik der Wasserversorgung. I. Der Druck in den Leitungsbahnen von Freilandpflanzen. *Ber. Deutsch. Bot. Ges.* 30: 576-580. 1912.

² Livingston, B. E., and Brown, W. H., "Relation of the daily march of transpiration to variations in the water content of foliage leaves." *Bot. Gaz.* 53: 309-330. 1912.

³ Lloyd, F. E., "The relation of transpiration and stomatal movements to the water content of the leaves of *Fouquieria splendens*." *Plant World* 15: 1-14. 1912. *Idem.*, "Leaf water and stomatal movement in *Gossypium*, and a method of direct visual observation of stomata *in situ*." *Bull. Torrey Bot. Club* 40: 1-26. 1913.

⁴ Shreve, Edith B., "The daily march of transpiration in a desert perennial." *Carnegie Inst. Wash. Pub.* 194: Washington, 1914.

above, was carried out in an arid region, with high transpiration rates, but the results of Renner were obtained in a very moist summer in Munich, so that it appears to be fairly well established that this phenomenon is general in plants. Of course, incipient drying is more pronounced with high atmospheric evaporating power and intense sunshine than with aerial surroundings of less aridity, and it is less pronounced in plants with low transpiring power than it is in less xerophilous forms.

From Renner's experiments, and also from those of Livingston and Hawkins,⁵ it appears that the rate of absorption of water by plant roots is determined by two conditions, which may be called, respectively, the absorbing power of the roots (internal) and the supplying power of the soil, or other medium in which the roots lie (external). It also appears that the internal one of these conditions (absorbing power of the roots) is at least partly controlled by the degree of incipient drying occurring in the plant, which, in turn is partly dependent upon the rate of transpiration. Other conditions being unchanged, the plant takes up more water from the soil when the transpiration rate is high than when it is lower. If incipient drying becomes sufficiently pronounced its presence is made evident, first by loss of turgor in the plant, then by temporary wilting⁶ (from which the wilted tissues may recover when transpiration is subsequently decreased), then by permanent wilting⁷ (from which the plants

⁵ Livingston, B. E., and Hawkins, Lon A., "The water relation between plant and soil." *Carnegie Inst. Wash. Pub.* 204: 5-48. Washington, 1915.

⁶ Brown, W. H., "The relation of evaporation to the water content of the soil at the time of wilting." *Plant World* 15: 121-134. 1912.

⁷ Briggs, L. J., and Shantz, H. L., "The wilting coefficient for different plants and its indirect determination. *U. S. Dept. Agric. Bur. Plant Ind. Bull.* 230: 1912. Caldwell, J. S., "The relation of environmental conditions to the phenomenon of permanent wilting in plants. *Physiol. Res.* 1: 1-56. 1913. Shive, J. W., and Livingston, B. E., "The relation of atmospheric evaporating power to soil moisture content at permanent wilting in plants. *Plant World* 17: 81-121. 1914.

cannot recover without special treatment), and finally by death and actual desiccation.

Incipient drying of leaves, whether they show any signs of wilting or not, may be said to be due to inadequate water supply to these organs; no matter how great might be the rate of foliar water loss, the transpiring cells should not suffer any diminution in their water content if the rate of entrance of water into these cells were only sufficiently great. The question therefore arises, as was mentioned by Livingston and Hawkins, to what extent is this inadequacy in the rate of foliar water supply to be considered as due to inadequate water supplying power of the soil, and to what extent may it be due to inadequate absorbing power of the roots and inadequate conducting power of the stems, petioles, etc.? In wilting leaves, for example, is the insufficient rate of water supply due to an external condition in the soil or to an internal condition, within the plant body?

This is a very important question, both with regard to the general problem of plant water relations and with respect to the practical problem of drought resistance in plants. A quantitative answer for plants growing in the open is of course impossible at present, but some light has been thrown upon the consideration of this question by some experiments recently carried out in the Laboratory of Plant Physiology.⁸ The matter in hand was approached by making the water-supplying power of the root surroundings very great; the test plants were grown in water-culture instead of in soil, so that the external resistance offered to water absorption by the root surfaces may be considered as practically nil and therefore constant. Under such conditions the actual rate of water absorption must be very nearly proportional to the absorbing power of the root system.

Two methods were employed, for both of which the transpirational rates were determined by weighing, in the ordi-

⁸ Mr. E. S. Johnston carried out the manipulations in these experiments.

nary way. By one method the absorption rates were determined as volumes, the plant being sealed into a bottle completely filled with the nutrient solution and furnished with a burette for measuring the volume of water absorbed. Temperature changes were corrected for by means of readings taken from a similar arrangement of bottle and burette without any plant. By the other method arrangement was made by which the plant could be suspended from the balance arm, its roots in the culture solution, with the surface of the latter always at the same mark on the basal part of the stem when the balance was in equilibrium. Thus, the buoyancy tending to lift the plant was very nearly the same at all weighings. During this weighing the split cork otherwise closing the culture jar was removed. Observations were obtained usually at hour intervals, from before daylight in the morning to late in the evening. The plants used were: *Coleus blumei*, *Fagopyrum esculentum* (buckwheat) and *Mimosa pudica* (sensitive plant). The experiments were carried out in an experiment greenhouse, in the autumn and early winter. The nutrient solution employed was of the Shive 3-salt type, apparently physiologically balanced as to salt proportions, and its total osmotic concentration was about 1.75 atmospheres. The results of eight tests, at different times of the year, may be briefly stated as follows.

(1) Sept. 20, clear sky. Buckwheat plant. Transpiration was greater than absorption for the period 8:50 a. m. to 1:50 p. m., incipient drying amounting to 0.63 g. Absorption was greater than transpiration for the period 1:50 to 5:50 p. m., the plant gaining in weight 0.15 g. Wilting began during hour ending 10:50 a. m., when incipient drying amounted to 0.27 g. Transpiration for this hour was 0.81 g. and absorption was 0.59 g. Transpiration for last hour of incipient drying was 0.98 g. and absorption was 0.96 g. Five out of six leaves were permanently wilted and never recovered.

(2) Sept. 21, clear sky. Buckwheat plant. Transpiration was greater than absorption for the period 9:20 a. m. to 1:20 p. m., incipient drying amounting to 0.24 g. Absorption was greater than transpiration for the period 1:20 to 9:20 p. m., the plant gaining in weight 0.38 g. Wilting began during hour ending 10:20 a. m., when incipient drying amounted to 0.08 g. For this hour transpira-

tion was 1.36 g. and absorption was 1.28 g. Transpiration for the last hour of incipient drying was 1.26 g. and absorption was 1.18 g. No permanent wilting occurred.

(3) Sept. 23, cloudy or partly cloudy. Buckwheat plant. Absorption was greater than transpiration for the period 6:50 to 7:20 a. m., the plant gaining 0.03 g. Transpiration and absorption were equal (0.08 g.) for the period 7:20 to 7:50 a. m. Transpiration was greater than absorption for the period 7:50 a. m. to 2:20 p. m., incipient drying amounting to 0.59 g. Wilting began during hour ending 10.20, when incipient drying amounted to 0.33 g. Transpiration for this hour was 0.56 g. and absorption was 0.44 g. Transpiration and absorption for the period of incipient drying (7.50 to 9.20 a. m.) were 0.67 and 0.46 g.; for the last period of incipient drying (12.30 to 2.20 p. m.) they were 1.49 and 1.43 g., respectively. Three out of five leaves were permanently wilted and never recovered.

(4) Nov. 3, clear sky. Dark red Coleus plant. Transpiration and absorption were equal (0.29 g.) for the hour 7:30 to 8:30 a. m. Transpiration was greater for the period 8:30 to 11:30 a. m., incipient drying amounting to 0.35 g. Absorption was greater for the period 11:30 a. m. to 7:30 p. m., the plant gaining in weight 0.68 g. Transpiration and absorption were equal (0.16 g.) for the period 7:30 to 9:30 p. m. No wilting was noted. The evaporating power of the air was 1.02 cc. (per hour, from the Livingston standard white spherical atmometer) for the first hour of incipient drying. Transpiration for this hour was 0.76 g. and absorption was 0.70 g.

(5) Nov. 4, cloudy. Dark red Coleus plant. Transpiration and absorption were equal (0.11 g.) for the period 5:30 to 7:30 a. m. Transpiration was greater for the period 7:30 a. m. to 2:30 p. m., incipient drying amounting to 0.47 g. Absorption was greater for the period 2:30 to 5:30 p. m., the plant gaining in weight 0.10 g. No wilting was noted. The atmometric index for first hour of incipient drying was 0.33 cc. Transpiration for this hour was 0.10 g. and absorption was 0.01 g.

(6) Nov. 16, clear sky. Two buckwheat plants bound together at base. Transpiration was greater than absorption for the period 9:30 to 11:30 a. m., incipient drying amounting to 0.17 g. Absorption was greater for the period 11:30 a. m. to 10:30 p. m., the plants gaining in weight 0.33 g. No wilting was noted. Atmometric index for last hour of incipient drying was 0.9 cc. Transpiration for this hour was 1.83 g. and absorption was 1.79 g.

(7) Nov. 16, clear sky. Dark red Coleus plant. Transpiration was greater than absorption for the period 9:45 a. m. to 3:45 p. m., incipient drying amounting to 0.89 g. Absorption was greater than transpiration for the period 3:45 to 7:45 p. m., the plant gaining in weight 0.78 g. No wilting was noted. The atmometric index

for last hour of incipient drying was 1.3 cc. Transpiration for this hour was 0.38 g., and absorption was 0.11 cc.

(8) Dec. 1, cloudy. *Mimosa* plant. Transpiration was greater than absorption for the period 7:55 a. m. to 3:55 p. m., incipient drying amounting to 2.97 g. Absorption was greater than transpiration for the period 3:55 to 5:55 p. m., the plant gaining in weight 0.27 g. No wilting was noted; the leaves were in night position at end of last hour. Atmometric index for last hour of incipient drying was 0.7 cc. Transpiration for this hour was 1.03 g. and absorption was 0.87 cc.

These data show very clearly that incipient drying, temporary wilting, and even permanent wilting of most of the leaves, may occur without any resistance at all to water-absorption by roots. These phenomena are here quite independent of such resistance to water intake as may be offered by unsaturated soils. Furthermore, in the complete absence of environmental resistance to water absorption by the root system, incipient drying may begin with an evaporating power of the air as low as 0.33 cc. per hour from the Livingston standard white sphere (Coleus, Nov. 4). Consequently, it does not require a high atmometric index to render the transpiration rate larger than the rate of absorption, in the case of some plants at least. The truth of this statement must be much more pronounced when the plant roots are surrounded by ordinary, fairly dry soils, which interpose an external resistance to water intake.

Unfortunately, atmometric observations were omitted in the first three tests, so that it is not possible to state what order of atmometric index values produced the wilting phenomena recorded for Sept. 20, 21 and 23. It is, of course, certain that these index values were not exceptionally high, however; the index for Baltimore is never high, and there was no artificial heat applied to the greenhouse on these days, so that the index value was not artificially raised. It is worth something to note that permanent wilting of most of the leaves of healthy buckwheat plants occurred in an unheated greenhouse in Baltimore on Sept. 20, with clear sky, and on Sept. 23, with partly cloudy sky.

Obviously, the absorbing powers of these plants were inadequate to supply water as rapidly as it was lost by transpiration during the hours when this loss was most rapid; the inadequacy was within the plant, an *internal* condition. It is suggested that the power of stem and petioles to *conduct* water from roots to leaves is here also inadequate, but on this point further experimentation will be required.

One definite advance in our knowledge of the water relations of plants is made by the data here considered; it may now be clearly stated that none of these three stages or degrees of incipient drying need *necessarily* be related to *soil-moisture conditions* at all. That they may *sometimes* be so related, when the soil about the root system fails to supply moisture to the root surfaces as rapidly as these are able to absorb it, is sufficiently clear on *a priori* grounds.

THE EFFECT OF DEFICIENT SOIL OXYGEN ON THE ROOTS OF HIGHER PLANTS

By B. E. LIVINGSTON AND E. E. FREE

During the last three years experiments have been in progress in the Laboratory of Plant Physiology on the oxygen requirement of the root systems of higher plants. A technique has been devised by which the root system, contained in normal soil, can be sealed off from the air and the soil atmosphere controlled in composition as may be desired. The aerial portions of the plants project into the atmosphere of the greenhouse. Water is supplied to the roots by means of the Livingston auto-irrigator.¹ It has been found that

¹ Livingston, B. E., "A method for controlling plant moisture." *Plant World* 11: 39-40. 1908. Hawkins, Lon A., "The porous clay cup for the automatic watering of plants." *Plant World* 13: 220-227. 1910. Livingston, B. E., and Hawkins, Lon A., "The water-relation between plant and soil." *Carnegie Inst. Wash. Pub.* 204: 5-48. 1915.

the response of the root-system to deficiency of oxygen in the soil atmosphere varies widely in different kinds of plants. Some species are injured by a very slight deficiency below the oxygen content of the general atmosphere. A swamp willow, probably *Salix nigra*, endures successfully the complete, or almost complete, exclusion of oxygen from its roots.

In the case of those plants which are injured by deficient soil oxygen it is interesting physiologically that the first effect of oxygen deprivation is an interference with the absorption of water by the roots. In the experiments the apparatus for the supply of water is so arranged that the amount of water taken up by the soil from the porous cups of the auto-irrigator can be measured for periods as short as one hour. The amount of water thus taken up depends in part on the temperature. The surface tension of the water films in the soil varies with temperature and this controls the amount of water held in the water-film system. However, this error disappears for periods the initial and final temperatures of which are nearly the same (for instance, the usual 24-hour period) and a correction can be made for the error in the case of shorter periods or other periods which do not satisfy this condition. When the temperature error is thus eliminated, the absorption of water from the auto-irrigator is closely parallel to the intake of water by the plant roots. With the plants that are sensitive to deficiency of oxygen in the soil air, it is found that the replacement of the normal soil atmosphere by nitrogen is followed within a few hours by nearly complete cessation of water-intake by the roots. With the most sensitive species tested, namely, *Coleus blumei* and *Heliotropium peruvianum*, this cessation of water-intake occurs always within 24 hours, usually within 12 hours, after the soil oxygen is removed. This time period varies with the individual plant, perhaps because of differences in the root-system but probably also because of differences in the completeness with which the soil oxygen originally present is replaced by the nitrogen. Since the oxygen must be displaced by washing out with

the nitrogen it is impossible to be sure that the replacement is ever absolutely complete at the beginning of the experiment.

The cessation of water intake, as shown by the stoppage of absorption from the auto-irrigator, is always the first sign of injury. With *Coleus* and *Heliotropium* it is followed in from one to six days by progressively lessened turgor of the shoot and leaves and finally by wilting and death. With *Coleus*, the admission of oxygen to the soil before death has actually occurred is followed by the slow recovery of the plant. *Heliotropium* does not so recover, even if oxygen is re-supplied before the wilting has become extensive or severe. With *Nerium oleander*, which does not wilt, the symptom of injury which follows next after the cessation of water intake by the roots is the yellowing and loss of leaves.

On removal and examination of the injured plants the root systems are found to be dead and the roots partly disintegrated. When the injury has been slight or recent, individual roots are determinately dead only in parts of their length, regions of brown discoloration alternating with regions of apparently healthy root. When *Coleus* is first injured and then revived by re-admission of oxygen it forms a new root system, the new healthy roots being clearly distinguishable from the older dead ones. These new roots start always from the base of the stem, as in a rooted cutting. They have never been observed to start from any portion of the older root system. If one begins with a *Coleus* plant which has a small root system, or with an unrooted cutting, or with a previously injured plant which will form new roots, it is possible to grow such a plant with a soil atmosphere somewhat below normal in oxygen content. In this case the shoot does not attain so large a size as the shoot of a normal control plant and is more susceptible to injury by drouth, as, for instance, by increase in the evaporating power of the air. The root system of such a plant, grown with deficient oxygen, is less developed than that of a normal

plant and the roots are long, thin and little branched, and range widely through the soil.

When *Coleus* plants of different sizes are deprived of soil oxygen, the cessation of water intake and the subsequent symptoms of injury appear first and are most severe on the plants which have the larger root systems. Again, a plant with a small root system will tolerate a lesser oxygen content in the soil than will a plant with a large root system. This implies that the crucial matter is the supply of oxygen per unit of root surface (or volume) and this is confirmed by the fact that a low oxygen content in a frequently changed atmosphere is less injurious than a higher oxygen content with less frequent changes.

The evidence suggests that the cause of injury by exclusion of oxygen from the roots is an interference with the respiration of the protoplasm of the root cells, resulting in the death of this protoplasm and the consequent failure of the roots to function as water absorbers for the plant. There is no reason, however, to assume any "vital" function of the root protoplasm in promoting water absorption. The protoplasmic coagulation which is, or accompanies, what is called death would constitute in itself a sufficient change to explain, on a purely physical basis, this effect on water absorption. The fact that the roots of at least one plant (*Salix*) appear to function normally in the absence of free oxygen raises the interesting question whether the respiration of these roots may not be anaerobic. It is impossible to answer this question finally. There is a theoretical possibility, in our experiments, of some small access of free oxygen from some source not now suspected. However, the sharp difference in the behavior of *Salix* and of *Coleus* under identical treatments suggests some important difference in the respiratory habits of the roots of the two species.

THE EXPERIMENTAL DETERMINATION OF A DYNAMIC SOIL-MOISTURE MINIMUM

By HOWARD E. PULLING

The conditions determining the rates of water movement in soils have long been recognized as of great importance in plant physiology, since they not only limit the amount of water a given root system may receive but also modify the effects of all soil processes upon rooted plants. In aerated soils water is moved by surface forces of the soil-moisture films. The magnitude of these forces is dependent upon the curvature of the film-air surfaces and not upon the amount of water in the soil, so that a soil volume might augment its water content at the expense of another contiguous soil volume that contained actually less water than the first. The *amount* of water that may be moved in unit time depends, however, also upon the amount of water in the films and a certain minimum should exist below which the quantity of water subject to capillary movement is too small to admit of any but negligible rates, regardless of the magnitude of the surface forces.

In aerated soils the water that responds to surface tension urge is accumulated around the points of contact of soil grains, so that the water adsorbed upon the surface of the grains, imbibed by the soil colloids and held as water of hydration by the grain constituents need not be considered in the present discussion. It is apparent that the greater the number of such points of contact between the soil grains in a given gross volume of soil, the greater should be the number of similar capillary masses of water and, consequently, the greater should be the amount of water in the soil when the rate of capillary movement becomes negligible. Accordingly a complete statement of this minimum for any soil may be represented not by a point but by a curve, in

which the conditions of the soil-air-water system are represented in terms of any two of the three components.

For convenience the components soil grains and water may be selected. The number of points of contact in any gross volume are determined by the number, size, shape and arrangement of the soil grains. In a sufficiently large volume (a few cubic centimeters, for arable soils) the soil grains may be considered as possessing an average density, size and shape, and this average will not change when other samples of the same soil are considered. Likewise if two samples of the same volume have the same number of soil grains, possessing the same average characteristics, it may be assumed that the average arrangement of grains is the same in each. This will be the more strictly true the longer the grains have existed in those volumes, since the forces of surface tension and gravity will tend to place them in the most stable positions. A relative measure of the properties of a mass of soil grains may thus be obtained for any one soil in terms of its dry weight per unit of gross volume, termed the packing.

The properties of the water masses in the soil may also be considered as being of average character and since these properties depend upon the shape and size of the water masses, which in turn depend upon the shape and size of the spaces about the points of contact of the soil grains, the number of these points and the amount of water in the soil, they will be sufficiently defined by the amount of water and the amount of soil contained in each unit of gross volume. When these amounts are determined for samples of any given soil, each uniformly packed and permitting only a negligible rate of water movement, the data are at hand for plotting the experimental approximation to the minimum moisture curve between the limits of packing encountered in the samples.

A method has been devised by the use of which samples of any given soil, each of approximately uniform packing, may be obtained with water contents so small that the rate of water movement is about 0.001 gram in 24 hours through

an area of 30 square millimeters. If the water contents per unit of gross volume of a number of such samples of the same soil are plotted as ordinates, and the corresponding dry weights are plotted as abscissas, the graph obtained by connecting the points is the positive portion of an approximately paraboliform curve that is symmetrical about the horizontal axis. This graph ascends steeply in the region of light packings, indicating the relatively large effect of adding more soil to a volume of low soil content. Its tendency to become horizontal indicates that, with dense packings, the addition of more soil but slightly increases the water content at the dynamic minimum.

The amount of water that exists in a given soil at a given packing above the minimum point for that packing is subject to capillary movement, so that the determination of the minimum is of great value in calculating the maximum rate at which water may move through the given soil under those conditions. Because the graphs vary in height and slope, at corresponding points, from one soil to another they should also serve as soil characteristics by which various soils might be recognized.

SOME UNUSUAL FEATURES OF A SUB-ARCTIC SOIL

By HOWARD E. PULLING

A preliminary survey of the ecological features of some sub-arctic forests during the past summer yielded information concerning the soils that emphasizes the need of including the physical root environment in an ecological study of such regions. The chief soil over the major portion of the area visited¹ was a gray to buff colored lacustrine clay

¹ The valleys of the Nelson river and its tributaries near Split Lake, which is situated in northern Manitoba, Canada, at about 56° north latitude and 96° west longitude.

formed from rock flour in the bed of ancient lake Aggasiz. The upper limit of frozen soil encountered during the summer varied from a depth of a few inches, near the water's edge on a shore with a north exposure, to about six feet on a slope well above the water line and with a southeast exposure. It is highly probable that one of the most effective agencies conditioning local distribution of plant species is the depth at which frozen soil is encountered. Large trees and other deeply rooted plants could not exist in soils made too shallow by the presence of perpetually frozen soil near the surface.

The soil of the spruce forest, which is the characteristic type of this region, is covered chiefly by sphagnum, often to a depth of several feet. Large amounts of water are held by the moss so that these forests resemble those of temperate regions at the borders of swamps and marshes. If the forest is situated on a hillside, however, the soil underneath the moss is usually dry and if exposed in windy weather will blow as dust. This may perhaps be explained in the light of knowledge of the conditions above and below the dry layer. This dry stratum rests upon frozen soil, which because of its lower vapor pressure and of other probably less effective properties, should continually absorb water from the adjacent, unfrozen soil. Thus, making the easily justified assumption that the soil was originally wet, the conditions exist for almost completely drying it, provided it should not regain the water lost. The light snowfall in this region would be unlikely to produce large amounts of water in the spring, especially on these slopes where drainage in the spring is rapid over the frozen surface of the soil, the relatively small amount remaining being conceivably retained by the highly absorbent sphagnum covering. The summer rains, which, although frequent, bring comparatively little water, are apparently no more than sufficient to supply the transpiration loss of the plants exposed to almost continuous winds and often to bright sunshine for many hours a day.

Roots penetrate this dry layer only to a slight extent,

although organic deposits occur down to the frost line. These deposits are lamelliform, and each appears to be continuous from its lowest point to the surface of the soil. Whether they originated from the decay of roots that had penetrated this layer while it contained more water than it does now, or whether they were formed by slow seepage from the surface, cannot be decided from the information at hand. The occurrence of small landslides in which dry soil was found above and below the layer in which the slipping occurred, indicates, however, that water may move in a thin sheet of soil and either form these deposits by carrying organic matter from the surface, or, finding them ready formed, traverse them to the deeper portions. Since these layers are rich in organic matter it is probable that their constituents would cohere when frozen, which is not true of the dryer soil about them. This may perhaps account for the statements often made that in the winter or spring, frozen soil may be encountered at the surface and also below it, in sheets, at intervals.

Whether due to this drying and being frozen in the dry condition, or to other more obscure causes, the soil of this dry layer is often flocculated to such a degree that it resembles a mass of small clay pellets. Even after wetting this flocculated soil retains its spherulate character.

THE GEOGRAPHICAL DISTRIBUTION OF THE CITRUS DISEASES, MELANOSE AND STEM-END ROT

By H. S. FAWCETT

A general survey of the citrus districts of the United States and Cuba has shown that the distribution-areas of some of the important fungus diseases are not coextensive with the areas where the host is cultivated. This fact is strikingly brought out by an examination of the distribution of some of the diseases that have been present in these regions for a long time.

An interesting example of an old, well-known disease with a rather limited distribution is melanose, which is due to *Phomopsis citri*. The fungus produces small, brown pustules on the surface of rapidly growing leaves, twigs and fruit. It was discovered in 1892 and was first definitely described, by Webber, in 1897. At that time melanose was already a rather serious disease in the middle portion of the peninsula of Florida. During the past 20 years, citrus nursery stock has been freely interchanged between different parts of Florida, and thousands of acres in Cuba have been brought into citrus culture for the first time, the stock for planting being derived from Florida, and yet the area over which the disease is now of serious commercial importance is confined roughly between the parallels of $27\frac{1}{2}^{\circ}$ and $29\frac{1}{2}^{\circ}$ N. latitude in Florida.

Southward from this area melanose gradually becomes less and less severe and it finally disappears entirely, so that the southernmost citrus districts of the state are free from it. In Cuba, if the disease occurs at all, it is of no commercial importance; I was unable to find any evidence of it in the island in January, 1914. North of the Florida area of most serious injury, melanose occurs in a less severe form, and a mild form of the same disease has been reported for southern Alabama and Louisiana, but it is apparently not serious in these regions. No trace of this disease has ever been found in California.

The same *Phomopsis* that produces melanose also plays a part in the so-called stem-end rot of mature or nearly mature citrus fruits, and it is an interesting fact that this fruit rot has never been known to be serious outside of the areas where melanose is also of commercial importance. Like melanose, stem-end rot has not been reported as occurring either in Cuba or in California.

The reasons for the peculiar distribution of *Phomopsis citri*, as above described, are not at all understood, and we cannot regard our knowledge of melanose and stem-end rot as at all nearly complete until a properly substantiated ex-

planation of these geographical limitations may be found. Such problems as this are worthy of serious attention. Some of the logical possibilities of this particular case may be mentioned, by way of preparing for further observations and for constructive experimentation.

One possibility that always presents itself in connection with a limited geographical distribution of any parasite is that sufficient opportunity or time may not yet have been afforded for the parasite to become distributed throughout the area occupied by the host. But this possibility seems not to apply in the present case. As has been mentioned, after melanose had become common in central peninsular Florida there took place a free interchange of many kinds of citrus nursery stock between Florida, on the one hand, and California and Cuba, on the other. Many carloads of young citrus trees were shipped from nurseries located in the Florida area where this *Phomopsis* was most virulent, no effective quarantine regulations were in operation at that time, and it is impossible that the fungus has not long since been thoroughly distributed. All or nearly all of the citrus varieties grown in Florida have been planted, at one time or another, in California, and the recent and extensive Cuban plantings have been made with nursery stock from Florida.

Of course, climatic conditions may furnish an explanation of the facts here dealt with, but the climatic relations of a fungus like *Phomopsis citri* are probably even more complex than are those of higher plants. For the growth of such a parasite it is not only necessary that the climatic conditions be suitable for this organism, but it is also essential that the complex of these conditions be naturally so arranged or balanced that the host-plant may be in just the proper state to favor the virulent development of the parasite. The time factor is especially important in the process of infection; it must happen that the host is in a condition to be readily infected just at the time when the fungus spores reach it.

One of the necessary conditions for the occurrence of melanose, when *Phomopsis* is present, appears to be a considerable degree of air humidity, at the season of most rapid growth of new shoots and of the fruit, and the absence of the disease in California may possibly be accounted for by the dryness of the air at the time when the trees are most susceptible to infection. This, however, does not seem to be a sufficient reason for the absence of melanose in the southernmost parts of Florida and Cuba.

Edgerton has recently emphasized the apparent bearing of temperature conditions on the occurrence of certain plant diseases in sub-tropical climates. He is convinced that the absence of anthracnose in beans grown at certain seasons in Louisiana is due to the fact that the average temperatures for those seasons are above the optimum for the growth of the pathogenic fungus. If this is true in the case of anthracnose it may also be true in the case of melanose. The first requirement for a test of this suggestion is, of course, some definite knowledge concerning the temperature relations of *Phomopsis* itself, and experimentation is now in progress in this direction.

PRELIMINARY NOTE ON THE RELATION OF TEMPERATURE TO THE GROWTH OF CERTAIN
PARASITIC FUNGI IN CULTURES

By H. S. FAWCETT

Interest in the temperature relations of plant growth is rapidly increasing, and, as improved methods become available, increasingly precise studies are being made of the influence of temperature upon growth as variously measured. The study upon which the writer is at present engaged aims to compare the temperature-growth curves for cultures of a number of fungi that produce diseases of citrus trees and that are confined to limited geographical areas. It is hoped

that the results obtained may be of value, not only in interpreting the geographical distribution and seasonal occurrence of these diseases, but in suggesting further means for their control.

A suitable solid medium in petri dishes is employed, a transfer (of spores or a small piece of mycelium) being made to the center of each culture dish, and the resulting growth is measured in terms of the 24-hourly increase in the mean diameter or radius of the nearly circular area occupied by the fungus. Various precautions are taken to have all conditions, excepting that of temperature, as nearly alike as possible throughout the entire investigation.

The preliminary work so far carried out has been confined largely to *Pythiacystis citrophthora*, which attacks both the trunk and fruit of the lemon tree. To illustrate the kind of results obtained, at the temperatures 10°, 20°, 28° and 33°C. the radial, 24-hourly growth-rates of this fungus were 2.5, 6, 7.5 and 2.6mm., respectively. For a rise of temperature from 10° to 20° the growth rate was thus somewhat more than doubled, from 20° to 28° it increased 25 per cent., and at 33° the rate was nearly the same as at 10°. This kind of a relation between the growth-rate and temperature was of course to be expected, and interest in this research will lie largely in the differences between the temperature-growth curves of the different fungi, especially in the differences between their optimum temperatures for growth.

Although bacteria and fungi, as studied by other workers, appear to exhibit gradually diminished growth-rates when temperature and the other environmental conditions are maintained unchanged for a long time, yet no such slowing down of growth has been encountered with this *Pythiacystis*; for example, the same growth-rate has been observed to continue unchanged for a period of eight days or more.

SYMPTOMS OF POISONING BY CERTAIN ELEMENTS, IN PELARGONIUM AND OTHER PLANTS

By E. E. FREE

In connection with other experiments on the effects of poisonous elements on plants, qualitative tests have been made of the symptoms of poisoning exhibited by the common cultivated geranium (*Pelargonium zonale*) and by several other plants, under the action of certain poisonous elements. The plants were grown in soil under ordinary greenhouse conditions. The poisons were applied by pouring the proper solutions on the soil when the latter was sufficiently dry to absorb and retain all of the added solution. Seven elements were applied to *Pelargonium* in five concentrations each. These were the following. Concentrations are in parts of the poisonous element per million parts of soil by weight.

	Concentrations
	p. p. m.
Arsenic, as trioxide (As_2O_3).....	2 to 500
Boron, as borax ($\text{Na}_2\text{B}_4\text{O}_7$).....	2 to 500
Copper, as sulphate (CuSO_4).....	4 to 1000
Iron, as ferrous sulphate (FeSO_4).....	20 to 5000
Lead, as nitrate ($\text{Pb}(\text{NO}_3)_2$).....	4 to 1000
Manganese, as sulphate (MnSO_4).....	8 to 2000
Zinc, as sulphate (ZnSO_4).....	8 to 2000

In addition to these seven elements the following were applied in one concentration only, namely 500 parts per million:—barium, as chloride (BaCl_2); bromine, as potassium bromide (KBr); cobalt, as sulphate (CoSO_4); chromium, as potassium chromate (K_2CrO_4); iodine, as potassium iodide (KI); lithium, as sulphate (Li_2SO_4); mercury, as mercuric chloride (HgCl_2); nickel, as sulphate (NiSO_4); silver, as nitrate (AgNO_3); uranium, as uranyl nitrate ($\text{UO}_2(\text{NO}_3)_2$); and vanadium, as chloride (VCl_2). All of these elements except iron were applied to *Impatiens sultani*, *Coleus blumei*

and *Vicia faba* as well as to *Pelargonium*. The first ten elements (arsenic, boron, copper, manganese, zinc, lead, mercury, iodine, chromium, and barium) were applied also to *Chrysanthemum frutescens*, *Bryophyllum calycinum* and castor bean (*Ricinis communis*). Except as noted, all applications were in the concentration of 500 parts of the poisonous element per million parts of soil. In order to avoid local injuries to the stem large applications were frequently divided and added in several portions at intervals of a few days.

The following elements gave no determinable poisonous effects on any plant, in the concentrations used: arsenic, barium, bromine, cobalt, copper, lead, manganese, nickel, silver, uranium, vanadium and zinc. A slight improvement of color and general condition was noticed in *Pelargonium* with manganese and zinc. There was also a slight, but unmistakable, stimulation of the growth of this plant by arsenic in the higher concentrations but this conceivably may have been due to some chemical action in making more available the phosphorus or other nutrients in the soil.

Pronounced toxic effects were observed with boron, chromium, iodine, lithium and mercury, and it is interesting that these effects were largely so specific as to permit immediate recognition of the particular poison by mere inspection of the plant. Thus on *Pelargonium* the effect of boron is the development of dark-green areas, 1 to 5 mm. wide, inward from the edges of the leaves. This altered strip gradually dries and hardens, without becoming brown, and the leaf falls after from one to four weeks. The dark-green coloration does not extend to the whole leaf. Lithium shows a somewhat similar behavior, but the altered area on the edge of the leaf is wider and is a light gray-green instead of dark green. It shows a very characteristic banding of the color in narrow light and dark lines parallel to the leaf edge. With iodine the leaves turn yellow on the edges and this yellowing gradually extends inward over the whole leaf. Not until the leaf has turned entirely yellow does it fall or wilt appreciably. Mercury produces a somewhat similar yellowing of the leaves,

but wilting begins immediately and the leaf usually falls long before it is entirely yellow. The first effect of chromium is a brown discoloration in the vascular bundles of the petioles and veins. This is followed by a change of the leaf color to a dark green, and the early fall of the leaves. The regularity and specificity of these changes is attested by many repeated observations on different leaves and different plant individuals. Similar specificities were observed with the plants other than *Pelargonium*. It seems probable, therefore, that the recognition of a poisonous agent by the specific symptoms of its action is as possible with these plants as with animal organisms.

Certain features of the localization of injury in the plants is suggestive of relations to transpiration. For instance, with boron and lithium on *Pelargonium* the limitation of injury to the edges of the leaves implies its occurrence only where the final evaporation of the water of the transpiration stream localizes the poison in a concentration sufficient to be toxic. A similar conclusion follows from the fact that injury occurs first, and sometimes only, on leaves of moderate age, that is on those which are in their period of most vigorous transpiration. Younger leaves and older leaves on the same plant are usually uninjured. Similarly, when a *Pelargonium* plant is poisoned but not killed, by either boron, lithium, mercury or iodine, new leaves produced thereafter do not show injury while they are young, but develop it after from two to six weeks of growth. The same observation was made with boron and iodine on *Chrysanthemum*. Further confirmation is the failure of *Bryophyllum*, which has a very low transpiring power, to show injury with any poison except boron. Even in this case the injury developed eleven weeks later than it did on *Pelargonium* and all the other plants. All of this evidence suggests that, in the concentrations used, the poisons were carried into the plant incidentally by the transpiration stream and produced injury only when and where the evaporation of the transpired water increased the concentration of the poison in a local tissue area. The symptoms observed

with chromium imply that it may form an exception to this behavior, but even with this element it was observed that *Pelargonium* leaves were injured only when of middle age; young and old leaves being unaffected.

THE EFFECT OF AERATION ON THE GROWTH OF BUCKWHEAT IN WATER-CULTURES

By E. E. FREE

In connection with other work on the oxygen requirements of plant roots experiments have been made on the relations between the degree of aeration of the culture solution and the growth of buckwheat in water-cultures. The plants were grown in quart jars in the usual manner, three plants to a jar. The solution was that found by Shive¹ to be the best for the growth of buckwheat. The experiment included 18 jars divided into six sets of three jars each. One set, used as control, was handled according to the usual technique, with free access of air to the solution. Another set was sealed, the seal about the young plants being made with a parafine-vaseline mixture according to the method of Briggs and Shantz.² With the third set, a slow stream of air was bubbled through the culture solution, a bubble about 5 mm. in diameter passing about once a second. The three remaining sets were treated in the same way with oxygen, nitrogen and carbon dioxide, respectively. Precautions were taken to remove deleterious impurities from the gases. Water evaporated from the culture solutions was replaced when necessary.

The cultures with oxygen, nitrogen and air showed no departure from the open controls or from the sealed cultures.

¹ Shive, John W., "A three-salt nutrient solution for plants." *Amer. Jour. Bot.* 2: 157-160, 1915.

² Briggs, L. J., and Shantz, H. L., "A wax seal method for determining the lower limit of available soil moisture." *Bot. Gaz.* 51: 210-219. 1911.

Rate of growth and weight of dry matter produced was essentially the same in all. All plants grew to maturity and nearly all set seed. It appears that the degree of aeration of the culture solution is without important influence on the growth of buckwheat under the conditions described; a conclusion that may have value in general water-culture practice.

It may be added that in the cultures treated with carbon dioxide the plants sickened and wilted within a few hours and died within a few days. In one case the stream of carbon dioxide was replaced after the first day by a stream of air. In this case the plants recovered partially but remained permanently smaller than the other plants of the experiment.

THE EFFECTS OF CERTAIN MINERAL POISONS ON YOUNG WHEAT PLANTS IN THREE-SALT NUTRIENT SOLUTIONS

By E. E. FREE and S. F. TRELEASE

A large part of the experimentation which has been done in the past on the effects of mineral poisons on plants is unsatisfactory and contradictory, for the reason that the nutrient materials available to the plants, in the soil or nutrient solution employed, were different in the different experiments. The reactions of plants to the various poisons appear to vary with such differences in the available nutrients. In connection with other work on nutrient solutions, tests have been made on the effects of certain poisonous elements on the growth of young wheat plants in water-cultures. The salt combination used in the nutrient solution was that found by Shive¹ to be best for the production of dry weight of

¹ Shive, J. W., "A three-salt nutrient solution for plants." *Amer. Jour. Bot.* 2: 157-160. 1915. *Idem*, "A study of physiological balance in nutrient media." *Physiol. Res.* 1: 327-397. 1915. (Especially p. 352-364.)

tops for wheat. The total concentration of the solution corresponded to an osmotic pressure of 1.75 atmospheres at 25° C. The technique was essentially the same as that employed by Shive.

The minimum concentrations at which the various poisons began to produce clearly marked injury, as indicated by smaller dry weights of tops, are given in the following table. Concentrations are given in parts of the poisonous element per million parts of the nutrient solution. In most cases the concentration at which injury begins is not sharply marked, and, therefore, the figures given have only approximate quantitative value.

<i>Element</i>	<i>Compound used</i>	Toxic Concentration of element. <i>p. p. m.</i>
Arsenic	trioxide (As_2O_3).....	1
Boron	borax ($\text{Na}_2\text{B}_4\text{O}_7$).....	10
Cobalt	sulphate (CoSO_4).....	7
Copper	sulphate (CuSO_4).....	1
Manganese	sulphate (MnSO_4).....	1000
Mercury	bichloride (HgCl_2).....	40
Nickel	sulphate (NiSO_4).....	5
Vanadium.....	chloride (VCl_2).....	20
Zinc	sulphate (ZnSO_4).....	100

Experiments were made also with lead, as lead nitrate ($\text{Pb}(\text{NO}_3)_2$), and with uranium as uranyl nitrate ($\text{UO}_2(\text{NO}_3)_2$), but both of these elements were precipitated by the constituents of the nutrient solution. The maximum concentrations obtainable in the solution were approximately 100 parts per million in case of lead and 20 parts per million in the case of uranium. Neither of these was toxic.

A slight stimulating effect, indicated by greater production of tops, was observed with manganese, between the concentrations of 4 and 20 parts per million, and with vanadium, between 2 and 7 parts per million. There was a clear stimulation in the uranium cultures above a concentration of 50 parts per million of uranium, but it is possible that this was

due to the nitrate in the uranium salt. No stimulation was observed with any other of the elements tested.

This failure to secure determinable stimulating effects with most of the elements is surprising and is contrary to the results of many previous investigations. It seems possible that it may be due to the fact that the Shive solution, in the concentration and salt proportions employed, is itself slightly toxic because of its high content of magnesium. This solution, although it gives the best production of dry weight of tops, produces plants many of which show the morphological modifications characteristic of magnesium poisoning.² These observations form one of several bits of evidence which suggest that the best growth of a plant, as measured by production of dry matter, occurs only when the plant is slightly poisoned. It may be a general rule that increased growth is the first response to agents or circumstances which would prove injuriously toxic in greater concentration or on longer exposure.

We have found some confirmation of this suggestion in our experiments on the effect of boron on Canada field pea. Using the Shive solutions containing salt proportions other than the ones above referred to, and adding borax to these solutions, considerable stimulations were obtained. The experiments need to be extended and confirmed, but the present indication is that borax is stimulating in those nutrient solutions which contain less magnesium than the one giving greatest dry weight of tops. In other words, slight poisoning, such as that caused by magnesium or boron, is essential for the production of the greatest dry weight of tops. Either magnesium or boron will serve. Probably other poisons would be equally efficacious.

² Shive, *loc. cit.* (2), p. 370-374. Tottingham, William E., "A quantitative chemical and physiological study of nutrient solutions for plant cultures." *Physiol. Res.* 1: 133-245. 1914.

LEAF-PRODUCT AS AN INDEX OF GROWTH IN SOY-BEAN

By F. MERRILL HILDEBRANDT

It has been pointed out by McLean¹ that the sum of the products of the length and breadth of all the leaflets on a soy-bean plant 4 weeks old is approximately proportional to the total leaf area of that plant, and he adds that the leaf area is itself nearly proportional to the total dry weight of stem and leaves. The sum just mentioned has been called the leaf-product by the same writer, his observations being based on measurements obtained at two stations in Maryland, Easton and Oakland, in the project carried out during the summer of 1914 by the Maryland State Weather Service in co-operation with the Laboratory of Plant Physiology of the Johns Hopkins University. That project included similar studies of the relation of plant growth to climatic conditions at seven other stations in Maryland, besides Easton and Oakland, and the present paper aims to bring out the fact that this interesting relation between leaf-product, leaf area and dry yield of tops applies generally to the soy-bean data for all nine stations.

If the method proposed by Livingston² and McLean, of employing the growth rates of standard plants as indices for the comparison of different climates as these influence plant growth in general, is to be of value, it is of course necessary that suitable plant characteristics be chosen for measurement in determining the growth rates, and it is desirable that the measurements be such as may be made from time to time without injury to the plants. The most generally accepted

¹ McLean, F. T., "A preliminary study of climatic conditions in Maryland, as related to plant growth." *Physiol. Res.* 2: 129-208. 1917.

² Livingston, B. E., and McLean, F. T., "A living climatological instrument." *Science*, n. s. 43: 362-363. 1916.

criterion of plant growth, dry weight of tops, can be obtained but once for any individual plant, since the plant is destroyed during the determination. Also, the accurate determination of leaf area is very difficult unless the plants are destroyed. On the other hand, as McLean has emphasized, leaf dimensions may be obtained repeatedly during the development of the plant without serious danger of inflicting injury. It may therefore be of considerable importance if leaf area, and even dry weight, can be satisfactorily estimated for soy-bean by the employment of the leaf-product as an index.

The general procedure followed in obtaining the observational data upon which are based the results here considered has been described by McLean, who conducted all the cultures personally (see his paper cited above). For the present purpose it is sufficient to state that cultures, each of 6 soy-bean plants, were started from the seed every two weeks throughout the summer season; at each of the nine stations employed, and that plant measurements were taken after about two and after about four weeks of growth. Dry weight and actual leaf area were determined only for the four-week periods, the plants being then destroyed, but the lengths and breadths of all leaflets were obtained for both the two-week and the four-week periods. Consequently, to study the correlation between total leaf area and total leaf-product per plant, only the four-week data are available, and these are the ones here considered. Thus, each of the nine stations is represented by a series of consecutive four-week culture periods, each period overlapping on to the next preceding and next following one. A large number of different sets of climatic conditions is thus represented by the whole series for the nine stations, which includes 97 4-week culture periods in all.

The leaf measurements here dealt with have all been obtained by the writer from photographic contact prints made by Dr. McLean from the fresh leaves immediately after these were removed from the plants. Areas were obtained from the same prints with a planimeter. The leaflet length was taken from tip to junction of blade and petiole for each leaflet, and

the corresponding leaflet breadth was measured at the point of greatest width, at right angles to the long axis of the leaflet. Since soy-bean leaflets are approximately elliptical in form and since the area of an ellipse is proportional to the product of its axes, the leaflet-product (length times breadth) of any leaflet should be nearly proportional to the area of that leaflet. Whether this relation may hold during the growth of the leaflet under different sets of climatic conditions depends upon how nearly the elliptical form is retained. The sum of the individual leaflet-products of any plant, which is the total leaf-product for that plant, should be approximately proportional to the total leaf area of the plant, if the relation given above holds. In the discussion that follows it will be shown that such an approximate proportionality does exist in the case of the four-week soy-bean plants.

In order to find out whether the actual area of the leaves in these cultures was proportional to the leaf-products, the ratio of the two quantities was worked out for a number of the stations. It was found that the leaf-product divided by the leaf area gives a number that varies only slightly from the value 1.28. In other words, if we measure the two diameters of the leaflets of a four-week soy-bean plant, multiply these two numbers, and add the products, a number is obtained which, when divided by 1.28, closely approximates the actual leaf area of that plant. Instead of using the sum of the products of length and breadth as an index of the area per plant we may use the sum of the squares of the lengths of the leaflets or the sum of the squares of the breadths of the leaflets of the plant. The numbers thus secured do not, however, bear as nearly constant a ratio to the actual leaf area as does the total leaf-product, and hence neither is as satisfactory an index of the area as is the leaf-product itself.

One of the most interesting properties of the four-week soy-bean plant is that the dry weight of stem and leaves is proportional, approximately, to the total leaf area. Having, therefore, a means by which the leaf area may be conveniently

measured, it is possible to calculate the dry weight of the plant approximately, by multiplying the leaf-area by the proper constant. The proportionality between the weight of the plant and its leaf area is not quite so constant as that between leaf area and leaf product, but in the great majority of cases the variation in the ratio of dry weight to leaf area, from a constant value, is less than 10 per cent. The relations given hold over a very wide range of climatic conditions and for plants varying in height from 2 or 3 centimeters to 18 or 20 centimeters. Since none of the plants in these experiments were grown to maturity, it is impossible to say whether this relation holds up to that time.

From the foregoing facts it may be concluded that the dry weight and leaf area of soy-beans 4 weeks old from the seed can be determined approximately from their leaflet dimensions. Soy-bean should therefore be very suitable for use as a standard plant for the measurement of climate in the manner suggested by Livingston and McLean, since the rate of its growth can be approximately determined from easily obtained leaf measurements. Also, the properties of soy-bean given above should make it a useful plant for any piece of physiological research in which it is desired to know approximately the dry weight of the plant used, at various stages of its development.

A METHOD FOR APPROXIMATING SUNSHINE INTENSITY FROM OCULAR OBSERVATIONS OF CLOUDINESS

By F. MERRILL HILDEBRANDT

Air temperature, the evaporating power of the air, and sunshine intensity may be considered the main climatic conditions affecting plant growth and one of the first essentials in ecological, agricultural, and forestal studies is some means by which these may be measured in the field. We are already provided with instruments for measuring the first two,

but the means thus far available for measuring sunshine intensity are difficult to apply in field studies. A method is here presented by which a roughly approximate index of sunshine intensity during any period for any station may be made from records such as are kept by the observers of the U. S. Weather Bureau.

The total heat equivalent of the actual sunshine for any given period at a station is primarily a function of three terms: (1) the maximum possible number of hours of sunshine (determined by latitude and season); (2) the mean intensity of full sunshine for the period and station, expressed in terms of heat; (3) the condition of the sky, whether overcast, partly overcast or clear. The daily values for the first two of these terms vary in a regular manner throughout the year at any given place, and the ones for the third term are roughly stated in the observer's records, as just mentioned. It was desired to combine these three terms so as to get approximations of sunshine intensity for a number of different stations in Maryland for the summer of 1914, in order to make comparisons of the summer march of sunshine intensity with that of corresponding measurements of plant growth. This has been accomplished in the manner described below.

The first two terms are combined in the ordinates of the graph given by Kimball¹ for the maximum possible total radiation received per day at Mount Weather, Virginia. Since this station is at about the same latitude as the stations in Maryland, the ordinate values may be taken as approximate measures of the total radiation intensity for the corresponding dates at any place in the state. These values represent the total amount of heat, expressed in gram-calories per square centimeter of horizontal surface exposed, received from the sun and sky on clear days at Mount Weather. The method

¹ Kimball, Herbert H., "The total radiation received on a horizontal surface from the sun and sky at Mount Weather. *Monthly Weather Rev.* 42: 474-487. 1914. (See especially fig. 8, p. 484).

of using the graph and a weather observer's report for estimating sunshine will be best shown by an example.

Suppose it is desired to estimate the average daily sunshine intensity for some station in the general region of Mount Weather, for the first week of August. The average ordinate value for this week is first obtained from Kimball's graph. For periods as short as a week or two this may be done by averaging the values for the first and last days of the period, since the curve may be taken as a straight line for such short intervals. From the report of the weather observer at the place in question, the number of clear, partly cloudy, and cloudy days is next determined for the days August 1 to August 7, inclusive, and some arbitrary weighting is given to each kind of day. We may, for instance, call clear days whole days of sunshine, partly cloudy days half days of sunshine, and assume that cloudy days are days without any sunshine. The scheme of weighting adopted must, of course, be adhered to in all the estimates made for different periods and stations. The system of weighting given above was used in the studies for which this method of approximating sunshine was developed. By summing these weighted daily values a number is obtained which represents the equivalent number of clear days for the period considered. Suppose, in the example selected, that this equivalent number of clear days is 3.5, which is 0.5 of the total number of days in the period. The latter value may be termed "the coefficient of clear weather." By multiplying the average daily intensity value for clear days, as obtained from the curve, by this coefficient of clear weather a number is secured that is a rough approximation of the average daily sunshine intensity for the week.

While it is certain that solar radiation affects plants in other ways than through its heating effect, it is no less certain that by far the greater part of the energy of sunshine absorbed by plants is converted into heat (largely as latent heat of the vaporization of water), and it seems probable that the other effects produced upon the plant may be more or less proportional to the total energy equivalent of sunshine. The

method of measurement of light here given, although it is only a rough approximation and depends on the heating effect of the sunshine, has been shown, as a matter of fact, to give numbers rather definitely correlated with plant growth. It has been found, for instance, that the amount of dry substance produced per unit of leaf area in young soy-bean plants decreases from the beginning to the end of the growing season, in a manner which generally parallels a corresponding fall in the light intensity values as determined in the manner described above.

MOISTURE EQUILIBRIUM IN POTS OF SOIL EQUIPPED WITH AUTO-IRRIGATORS

By F. S. HOLMES

While the auto-irrigator devised by Livingston¹ has been employed by several writers,² for maintaining uniform moisture conditions in potted soils, the details of adjustment required by this device, for different soils and for maintaining different moisture contents, remain still to be worked out. In order to throw some light upon this general question, a study of three different soils was undertaken to determine the relation between the equilibrium point of the soil-moisture content and the number of irrigator cups employed.

One soil was a medium-fine white sand, one was a light

¹Livingston, B. E., "A method of controlling plant moisture." *Plant World* 11: 39-40. 1908.

²Hawkins, Lon A., "The porous clay cup for the automatic watering of plants." *Plant World* 13: 220-227. 1910. Transeau, E. N., "Apparatus for the study of comparative transpiration." *Bot. Gaz.* 52: 54-60. 1911. Livingston, B. E., and Lon A. Hawkins, "The water relation between plant and soil." *Carnegie Inst. Wash. Pub.* 204: 5-48. 1915. Hibbard, R. P., and O. E. Harrington, "Depression of the freezing-point in triturated plant tissues, and the magnitude of this depression as related to soil moisture." *Physiol. Res.* 1: 441-454. 1916.

clay loam, and the third was a mixture, of equal parts, by volume, of the other two. Pots of each kind of soil were equipped with auto-irrigators having respectively one, three and five porous cups, thus giving nine combinations. The containers were tinned sheet-metal cylinders approximately 15 cm. in diameter and 17 cm. in height. The porous cups were evenly distributed within the soil mass, when but one was used it occupied the center. A mercury tube was so arranged that all water entered the soil against a pressure of from 5 to 6 cm. of a mercury column. Evaporation was prevented by sealing covers on the containers with plastiline. The cylinders were filled to a uniform depth of 16 cm., an attempt being made to secure as uniform packing as possible throughout the entire series.

Weighings of the containers were made at intervals of two or three days, for the first twenty days, and thereafter at weekly intervals, to determine the rates at which water was being absorbed and to approximate the moisture content of the soil. Approximately three-fourths of the water taken up by the loam and by the sand-loam mixture occurred during the first ten days, but the sand took up only about one-half of its total amount in the same period. Approximate equilibrium of the soil moisture content was reached in about seventy-five days, in the case of the loam; in about eighty days in the case of the mixture; and in about ninety days in the case of the sand. The number of porous clay cups employed seemed to have no influence upon the length of time required for the attainment of equilibrium by either the loam or the loam-sand mixture. With the sand, however, the number of cups appeared to influence the length of this time period. With three cups equilibrium was reached sooner than with one, and with five sooner than with three.

When the weighings of the cylinders and observations on the water reservoirs showed that the soil had ceased to absorb water, the cylinders were opened and samples were taken for soil-moisture determinations. Two 1-cm., full-depth cores were taken from each container, one core from as near a cup

as possible, the other as far removed as possible. The average of the two was taken to be representative of the entire soil mass. Each sample was removed and dried in eight 2-cm. sections, so that it was possible to study both the vertical and horizontal distribution of the soil moisture in the cylinder. There was a horizontal as well as a vertical variation of small magnitude in the soil-moisture content of all the cylinders, the water content being almost always somewhat higher near the cups and at the bottom of the soil mass. The distribution of the moisture, both horizontal and vertical, was more uniform in the sand-loam mixture than in the sand, and also more uniform in the loam than in the mixture. The number of porous cups used had very little influence, if any, upon the soil moisture content of the loam; it varied as 100 : 106 : 103, for the containers having one, three and five porous cups, respectively. This influence of the number of cups was more pronounced in the case of the sand-loam mixture, the variation, with one, three and five cups, being 100 : 147 : 168. With the sand there was a still more marked effect, the moisture contents for the three cup numbers being 100 : 191 : 277 in this case. These variations are all smaller than the corresponding variations in the value of the ratio of cup number to soil mass, these values varying as 100 : 321 : 576, for all three soils. For the containers with three cups the actual average soil moisture content (on the basis of dry weight) was 11.0 per cent. for the loam, 5.2 per cent. for the mixture, and 1.1 per cent. for the sand.

With the pressure here used (averaging 5.5 cm. of a mercury column) the soil moisture content at equilibrium was too low for plant cultures in the sand and perhaps also in the sand-loam mixture. In the loam, however, it was surely high enough to supply plants with the water necessary for their growth under ordinary greenhouse conditions.

SEASONAL VARIATIONS IN THE GROWTH-RATES OF BUCKWHEAT PLANTS UNDER GREENHOUSE CONDITIONS

By EARL S. JOHNSTON

Seasonal variations in greenhouse plants are of considerable importance to plant growers as well as to experimenters in plant physiology, but it is especially with reference to physiological experimentation that this study was undertaken. When it is necessary to repeat an experiment on plant growth it often occurs that the results of the second experiment are in more or less pronounced disagreement with those of the first. Since the controlled external conditions must be regarded as the same for both experiments, such disagreement appears to be related either to initial differences in the plants used (internal conditions) or to uncontrolled external conditions as these vary with the season. The first of these possibilities is probably not as important as the second in most cases, for care is usually taken to select plants for the second experiment that are apparently similar to those used for the first. While this problem of similarity of internal conditions of different lots of plants is a very difficult one and is hardly susceptible of quantitative study at the present time, it is quite possible to carry out studies on the relation of growth to the usually uncontrolled (or only partially controlled) external conditions of a greenhouse, as these conditions change throughout the year. A portion of the results obtained from such study are here presented.

A set of similar water cultures was started every two weeks and each was continued for a period of four weeks, so that the periods of successive sets overlapped. A single set consisted of ten plants, each suitably supported in a glass jar containing about 425 cc. of nutrient solution. These jars were covered, to exclude most of the light from the plant roots. The solution was renewed at the middle of each four-week

period. At the end of each week several different kinds of measurements of the plants were made, and the data thus obtained were studied to bring out the seasonal variations in growth-rates. Since the solutions were alike for all sets and the seedlings used were selected for likeness, it is fair to suppose that observed differences in growth-rates, between the different sets of cultures, must have been mainly due to fluctuations in the uncontrolled conditions of the surroundings, such as temperature, light and the evaporating power of the air.

The experiments were carried out in one of the experiment greenhouses of the Laboratory of Plant Physiology. No artificial shade was applied to the greenhouse. Two sets of cultures were always carried out simultaneously, one under unmodified greenhouse conditions and the other in a cheese-cloth chamber in the greenhouse, but the data obtained from the chamber cultures will not be dealt with in the present paper. A continuously rotating table 76 cm. in diameter was used in each case, the jars standing near the margin of the table.

Japanese buckwheat, *Fagopyrum esculentum* Moench., was employed, and Shive's¹ three-salt nutrient solution, no. R 4C2 (total osmotic value 1.75 atmospheres), was used throughout the entire series. Aside from renewing the solution at the middle of the four-week period, water was always added at the end of the third week of growth, to bring the solution back to its original volume. When the transpiration rates were excessive a still further addition of water was made during the fourth week of growth, in order to prevent the root systems from becoming unduly exposed. The first experiment began Feb. 14, 1916.

Of the plant characteristics measured at the end of each four-week period of growth, only stem height, total dry weight and total area of the leaves (one surface only) are here con-

¹Shive, John W., "A study of physiological balance in nutrient media." *Physiol. Res.* 1: 327-397. 1915.

sidered, the values obtained being expressed as averages per plant, for each of the four-week periods. The temperature conditions, the evaporating power of the air and the intensity of radiation were recorded for each of the two exposures, but these are left out of the present consideration.

The results obtained from these three plant measurements are shown in the accompanying table, wherein all the values are expressed in terms of the corresponding value for the period ending May 22. In this table the dates of beginning and ending of the several culture periods are shown in the first two columns. Each value given in the table represents an average growth-rate representing a single plant, for a time period of 28 days.

EXPERIMENTAL DATA

Beginning	Period Ending	Stem Height.	Total Dry Wt.	Leaf Area	Av'ge of Wt. & Area
Feb. 14	Mar. 13	.73	.50	.63	.57
Feb. 28	Mar. 27	.83	.62	.81	.72
Mar. 13	Apr. 10	.85	.72	.77	.75
Mar. 27	Apr. 24	.94	.80	.76	.78
Apr. 10	May 8	.98	.89	.76	.83
Apr. 24	May 22	1.00 (67.5 cm.)	1.00 (1.338 g.)	1.00 (213.5 sq. cm.)	1.00
May 8	June 5	.93	.91	.93	.92
May 22	June 19	.83	.93	.98	.96
June 5	July 3	.73	.93	1.00 (214.1 sq. cm.)	.97
June 19	July 17	.77	.88	.88	.88
July 3	July 31	.97	.91	.92	.92
July 17	Aug. 14	1.04	.82	.83	.83
July 31	Aug. 28	.91	.67	.77	.72
Aug. 14	Sept. 11*	—	—	—	—
Aug. 28	Sept. 25	1.07	.76	.70	.73
Sept. 11	Oct. 9	.97	.55	.58	.57
Sept. 25	Oct. 23	.78	.34	.43	.39
Oct. 9	Nov. 6	.79	.36	.51	.44

The different kinds of growth-rates are seen to vary independently, from period to period, but two of the growth

* Data not obtained because of insect injury to plants.

criteria, weight and area, show variations that correspond rather closely. Both of these show high rates for the summer and low ones for the spring and autumn. Judged by dry weight of plant produced the growth-rate reached its maximum (1.34 g. per plant, in 28 days) with the period ending May 22, but this value remains high until after the period ending July 31. Judged by the total leaf area, the rate does not attain its maximum (214 sq. cm. per plant, in 28 days) until later, this occurring with the period ending July 3, but this value is high for the three preceding periods and for the two following. Roughly speaking, it may be said that these two criteria give rates that are proportional, and that they agree in indicating a period of very rapid growth, extending from about May 8 to about July 17. Before the period with its middle at May 8 the rates are lower, forming a generally ascending series, from the very low values of the early spring, and after the period with its middle at July 17 they decrease rapidly (with a low secondary maximum indicated for the period ending Sept. 25) to very low values in the autumn.

The rates of growth in height fail to show this sort of seasonal march; the maximum rate (49 cm. per plant, in 28 days) being shown for the period ending July 3, but this rate also has very low values for the periods ending March 13, Oct. 23 and Nov. 6. By this criterion, the maximum for the period considered (72.5 cm. per plant, in 28 days) occurs with the period ending Sept. 25, but pronounced secondary maxima are shown for the periods ending May 22 and Aug. 14. This rate of growth in height appears to vary considerably from period to period, but in a manner entirely independent of the general advance of the season and quite independent of the variations in rates of increase in dry weight and in leaf area. As far as these data go, it therefore appears that there is nothing in the usually uncontrolled external conditions of a greenhouse in this climate, that may be expected to produce a regular march of growth-rates in

height, for healthy buckwheat plants, during the spring, summer and autumn.

McLean² has pointed out the approximate proportionality of the rates of production of dry weight and leaf surface, for the first four weeks of growth of soy-bean plants, and he also found that the rate of stem elongation varied quite differently from the rates of production of dry weight and surface. It may be of fundamental significance that two plants as widely different, in many other respects, as are buckwheat and soy-bean, exhibit these remarkable agreements in the manner of variation in these three growth-rates with differences in the climatic conditions of the environment.

The general agreement between the seasonal variations shown by the rates of increase in dry weight and in leaf area is so marked that it appears quite permissible to combine these two criteria by averaging their relative values, to give a single value representing both together, and the averages so derived are given in the last column of the table. Of course, these two measurements of growth-rate are not directly commensurable, and the average values here introduced are to be regarded merely as numerical indices of the rates of growth. This value has its maximum (1.00) for the period ending May 22, and it of course shows high value for the five following periods. Its minimum value (0.39) occurs for the period ending Oct. 23.

Of course there are many other considerations to receive attention in a study of this sort, but it already seems clear that a regular and pronounced seasonal variation in the rates of production of dry weight and leaf area may be expected in healthy buckwheat plants growing in a greenhouse in this kind of climate, although the same nutrient medium is always employed. If the weight-area indices be represented

² McLean, Forman T., "A preliminary study of climatic conditions in Maryland, as related to plant growth." *Physiol. Res.* 2: 129-208. 1917.

graphically they give only comparatively slight variations from a smooth curve and the actual graph may readily be smoothed to give such a curve. After this has been done the ordinates of the smoothed curve, corresponding to the various culture periods, may be measured, and the series of graphically derived values thus obtained may be taken as a tentative scale to indicate approximately the relative growth-rates to be expected for this plant in these general surroundings. Of course, the seasonal march of the climatic conditions in this particular greenhouse must be expected to vary from year to year, and it surely varies from greenhouse to greenhouse; nevertheless, the tentative scale derived as just described may be of value in several ways.

For the first sixteen four-week periods of the present study, beginning with Feb. 14, as given in the table presented above, these relative seasonal indices of growth-rate (by either dry weight or leaf area, which appear to be proportional, or by their average) are respectively as follows: 61, 71, 79, 86, 91, 96, 99, 100, 99, 96, 92, 87, 81, 75, 68, 61. In this scale of growth-rate values the maximum (100) occurs for the period ending June 19, and it represents actual average growth-rates, as obtained in this study, of 1.24 g. of dry weight and 209 sq. cm. of leaf area (one surface only), per plant, per period of 28 days. While these derived results are extremely tentative and probably only very roughly approximate, it is clear that we have here a new kind of description of the climatic conditions of this greenhouse for the spring, summer and autumn of 1916, these conditions and their seasonal march being described in terms of their ability to produce dry material and leaf surface in the standard plant here employed.

By such a method as this the climatic plant-producing power for any four-week period may be directly compared with that of any other similar period, no matter when or where these periods occur, the standard plant being used as an automatically integrating instrument for the measurement of

the effective climatic conditions. This general method for the comparative study of climatic conditions has been suggested by Livingston and McLean³ and a first attempt at its employment was carried out by McLean in the paper already mentioned.

ON THE RELATION OF CHLORINE TO PLANT GROWTH

By W. E. TOTTINGHAM

As a result of experiments conducted early in the development of the water-culture method, chlorine has been considered as one of the unessential elements for the growth of plants in general. Nevertheless, all seeds contain more or less of this element and in no instance has a plant been limited to this original source of chlorine through successive generations, so that it may still be said that the question here raised has never been really tested. Practically all soils contain considerable amounts of chlorine in the form of chlorides and its occurrence in plants appears to be confined to this form. That this element may have important effects under some conditions, when applied as an agricultural fertilizer, is indicated by a common practice in some parts of Europe, of adding common salt to stimulate the growth of mangel-wurzel and of mixed meadow grasses, but the manner in which this effect is produced has not been made clear. It has been observed that unrestricted application of chlorides may lead to poisoning of the soil, and agriculturists have been advised specially against the use of potassium chloride as a source of potassium for tobacco, the potato and the sugar beet. European investigators have reported a decreased content of starch in the potato tuber as a result of the substitution of this salt for potassium sulphate.

³ Livingston, B. E., and McLean, F. T., "A living climatological instrument." *Science*, n. s. 43: 362-363. 1916.

The investigations here considered in a preliminary way were planned to supplement our knowledge of this subject. They are as yet in early stages of progress, having been begun under the auspices of the Wisconsin Agricultural Experiment Station. It was purposed to measure the responses of various plants, in form and in the weight of plant material produced, to the application of certain chlorides, and to determine any specific results brought about by this application of chlorine, upon the chemical composition of the plants. Greenhouse cultures were grown in nutrient solutions, in pure sand and in Miami silt loam, and field cultures were grown in loam. It may be said of these greenhouse cultures, which were partly carried out in the winter, that, while growth is retarded by the decreased light intensities of the winter months, the partial control of climatic and soil conditions in such greenhouse cultures assures more reliable comparative results than are usually derived from field plots, with their natural fluctuation of climatic conditions from season to season and of fertility from plot to plot.

In the water-culture experiments, in the greenhouse, the plants were grown to maturity, in either Tottingham's or Knop's nutrient solution,¹ containing $\text{Ca}(\text{NO}_3)_2$, KNO_3 , MgSO_4 and KH_2PO_4 , in proper proportions, with a trace of iron as FePO_4 . The former had a total osmotic concentration value of about 1.75 atmospheres (0.4 per cent. of salts by weight) and the total osmotic value of the latter was about 0.9 atmospheres (0.2 per cent. of salts by weight). In some cases chlorine was introduced by replacing the MgSO_4 of the 4-salt solution with a molecularly equivalent quantity of MgCl_2 , in other cases KNO_3 was replaced by KCl , and in still other cases NaCl was superimposed upon the salts usually present. Replacement of MgSO_4 by MgCl_2 resulted in an increased length of roots, for pea, wheat and clover, amount-

¹ Tottingham, W. E., "A quantitative chemical and physiological study of nutrient solutions for plant cultures." *Physiol. Res.* 1: 247-288. 1914.

ing to from 100 to 300 per cent. This gain in root length was correlated with somewhat smaller gains in dry weight. With wheat and clover the production of dry weight of tops was depressed by this treatment but the percentage of nitrogen contained in the dry tops was unaffected. It will be noted that the interpretation of these effects is complicated by the fact that sulphur was absent where chlorine was present in the solution.

Buckwheat was grown in Knop's solution modified by having KNO_3 partly or wholly replaced by KCl , thus avoiding the omission of sulphur. Such treatment led to a slightly increased production of stem and root when the replacement was only partial, but complete replacement depressed the root length and the dry weight of roots and leaves, the amount of water lost by transpiration being proportionately decreased. Total replacement of KNO_3 by NaCl depressed growth more than when KCl was used and transpirational water loss was more than proportionately decreased. Comparison with the necessary control solutions indicated that this effect is to be considered specific for the NaCl molecule, an observation which adds to the accumulating evidence that molecules must be taken into consideration, and not ions only, in dealing with the relations between the plant and the solutes of a nutrient solution. The conclusion of earlier investigators, that chlorine must be added to the nutrient solution for the complete development of buckwheat, finds no support in the present work.

The sand cultures of this study (also in the greenhouse) were conducted on 20-kilogram portions of sand, in open boxes with paraffined inner surfaces. The insoluble salts were incorporated with the dry sand and the others were added in successive portions of solution. The total application of salts was about 0.25 per cent. of the dry weight of the sand. With mangel-wurzel, an increase of from 40 to 120 per cent. in the dry weight of roots resulted from the application of KCl in a complete fertilizer ration, but greater in-

crease followed where NaCl was superimposed upon the usual complete ration.

For the greenhouse cultures in Miami silt loam, fifteen or twenty kilograms of air-dry soil were employed, in cypress boxes, the salts being added as in the case of the sand cultures. The total application of salts approximated from 0.06 to 0.15 per cent. of the dry weight of the soil.

The sugar beet produced 50 per cent. more dry substance (root) when chlorine was included with the usual salt ration than when the ration without chlorine was used. The glucose content of the root was increased somewhat, percentage on the basis of dry weight, but the sucrose content was uninfluenced by this treatment. Preliminary experiments with the radish indicate that it is little affected by the chlorine supply, while the growth of the carrot is stimulated and that of the parsnip is depressed as regards content of dry matter and percentage of sugars. Similar experiments with the potato ("Triumph" and "Rural New Yorker" varieties) gave the same dry weights of tubers, whether potassium was supplied as the chloride or as the sulphate.

In the field experiments, sugar beet roots showed an increase of from 10 to 30 per cent., by weight, where NaCl was applied to the soil at the rate of from 260 to 520 pounds per acre, as compared with those of the unfertilized plot. The glucose content was increased, but that of sucrose was unaffected by this treatment.

The potato ("Triumph" variety) produced the same yield, both of total and marketable tubers, whether supplied with potassium as KCl or as K_2SO_4 , in the complete fertilizer ration. The addition of NaCl without other salts depressed the yield. Another experiment with potato ("Rural New Yorker" variety) showed that the starch content and cooking qualities of the tuber were the same whether potassium was supplied as KCl or as K_2SO_4 , in the complete fertilizer. Fertilization with NaCl alone gave tubers of lower starch content and poor quality. It thus appears that the depress-

ing effect of chlorine, as reported² for starch content and cooking quality of potato tubers, does not obtain under all conditions of culture, and fails to make itself manifest with the climatic and soil conditions of these experiments.

The results outlined above leave the question of the influence of the chlorine ion and chlorides upon plants still in a very complicated and unsatisfactory condition. Perhaps the most valuable general conclusion that can be drawn from a review of all the work so far reported upon this subject, is that the influence here considered appears to be impossible of any general statement. It appears that the effect of chlorine upon any given plant depends upon the nature of the plant, upon the soil conditions (aside from chloride content) and upon the conditions of the surroundings generally classed as climatic. It may be that each particular case of acceleration or retardation of growth processes by chlorine presents a special problem, and that broad generalizations are not to be expected until much progress has been made toward the interpretation of environmental complexes as a whole; for the present, we are constrained to study these conditions piecemeal. It seems that the promise of progress in these very complicated problems of agricultural science lies largely in more complete experimental control of the very numerous conditions that make up the environment of the plant. It is the summed or integrated effects of all of these that is registered by our plants in growth and crop production.

² For example, see: Süchting, H., "Ueber die schädigende Wirkung der Kalirohsalze auf die Kartoffel." *Landw. Versuchsst.* 61: 397-449. 1905.

A STUDY OF SALT PROPORTIONS IN A NUTRIENT
SOLUTION CONTAINING CHLORIDE, AS RELATED
TO THE GROWTH OF YOUNG WHEAT PLANTS

By S. F. TRELEASE

Chlorine has been considered an unnecessary element in the nutrition of most plants, but it seems to have produced a beneficial influence in certain cases that have been recorded. There is some practical as well as scientific interest in the question thus raised, since potassium chloride is frequently used as an agricultural fertilizer, and the influence of the chlorine thus put into the soil may not be without importance. In the experiments of which this is a preliminary report the chlorine ion was introduced into nutrient solutions that already contained all the essential elements usually absorbed by plant roots. These essential elements (N, S, P, Ca, Mg, K, and Fe) may be supplied to the young wheat plants as a nutrient solution containing the three salts $\text{Ca}(\text{NO}_3)_2$, MgSO_4 , and KH_2PO_4 , with a trace of iron as FePO_4 . To introduce chlorine, KCl was added to the list just given, thus making a 4-salt solution. A solution made from these four salts was used by Knop and Nobbe, and Grafe¹ recommends these same salts as most generally useful. Detmer² employed one set of proportions of these four salts, and this solution has been designated by Tottingham³ as Detmer's solution. In the experiments considered in this paper the same general methods were used as were

¹ Grafe, V. "Ernährungsphysiologisches Praktikum der höheren Pflanzen." Berlin, 1914.

² Detmer, W., "Practical plant physiology." Translated by S. A. Moor. London, 1898.

³ Tottingham, W. E., "A quantitative chemical and physiological study of nutrient solutions for plant cultures." *Physiol. Res.* 1: 133-245. 1914.

employed by Tottingham and by Shive.⁴ The total concentration of the nutrient solution corresponded to an osmotic pressure of approximately 1.6 atmospheres at 25° C., and the relative proportions of the four component salts were varied in all possible ways, by increments of one-tenth of this total concentration. Eighty-four different solutions were thus included in each complete set; all of these had approximately the same total osmotic concentration, but no two had the same relative proportions of the four component salts. Six plants were grown in each culture, and the solutions were renewed every four days.

The various salt proportions proved to be very different in their ability to produce growth of the young wheat plants. As has been found by other writers, the solution giving the greatest dry yield of tops is not the one giving the greatest yield of roots, and the solution producing the highest dry weight of tops and roots together has still another set of salt proportions. The highest dry yield of tops was obtained with the following partial volume-molecular concentrations of the four main constituent salts: 0.0067M KCl, 0.0138M KH_2PO_4 , 0.0047M $\text{Ca}(\text{NO}_3)_2$, and 0.0081M MgSO_4 . A trace of iron was, of course, added, as a suspension of ferric phosphate.

This highest yield of wheat tops with the 4-salt solution containing chlorine was not higher, however, than was obtained, in these experiments, with the best salt proportions, without chlorine, of the Birner and Lucanus (Shive) 3-salt solution and of the Knop (Tottingham) 4-salt solution. If the best salt proportions are used in all three cases these three very different types of solutions give practically the same result. It therefore appears to be impossible to improve the growth of young wheat plants, as this occurs in Shive's and Tottingham's best salt proportions, by the introduction of

⁴ Shive, J. W., "A three-salt nutrient solution for plants." *Amer. Jour. Bot.* 2: 157-160. 1915. *Idem*, "A study of physiological balance in nutrient media." *Physiol. Res.* 1: 327-397. 1915.

chlorine into the solution. Furthermore, the best 4-salt solution with chlorine contains the three essential salts in nearly the same proportions as those in which they occur in Shive's best 3-salt solution, which has the following composition: 0.0180M KH_2PO_4 , 0.0052M $\text{Ca}(\text{NO}_3)_2$, and 0.0150M MgSO_4 . The main difference in this respect lies in the Mg/Ca quotient; in Shive's best solution this quotient has the value 2.88, and in the best 4-salt solution with chlorine it has the value 1.72. Both are characterized by relatively high proportions of KH_2PO_4 , and low proportions of $\text{Ca}(\text{NO}_3)_2$, which is rather surprising, since many nutrient solutions heretofore proposed have a relatively high concentration of $\text{Ca}(\text{NO}_3)_2$. In general, the occurrence of the morphological leaf modifications recognized as magnesium injury in such series as these (Tottingham, Shive) was not altered by the presence of the chlorine ion in the solution.

A marked improvement over Detmer's salt proportions was obtained in the present study. The best solution gave an increase in dry weight of tops of 27 per cent. and 20 per cent., respectively, over the yields obtained in two solutions of the present series closely resembling Detmer's in salt proportions. An even more marked improvement over the growth obtained with Detmer's exact proportions is reported by Shive, for his best 3-salt solution, which, as has been mentioned, gave practically the same yield as did the best 4-salt solution used in this study.

While it seems impossible to obtain higher top yields of these plants in the 4-salt solution containing chlorine, than in the 3-salt solution without this element, it should nevertheless be remarked that the presence of chlorine may diminish to some extent the retarding effect produced by the three salts of the essential elements when these are not in the best proportions. Thus, if we start with an unbalanced 3-salt solution, a proper addition of chlorine may sometimes accelerate the growth of the plants. The addition of a non-essential element may improve the physiological properties of a solution containing the essential elements in improper proportions.

Perhaps the main result of this study is, in general, that no matter whether we employ (1) the three salts KH_2PO_4 , $\text{Ca}(\text{NO}_3)_2$, and MgSO_4 , (2) the four salts KH_2PO_4 , $\text{Ca}(\text{NO}_3)_2$, MgSO_4 , and KNO_3 , or (3) the four-salts KH_2PO_4 , $\text{Ca}(\text{NO}_3)_2$, MgSO_4 , and KCl , if we use the *best proportions* of the salts in each case we may expect to obtain about the same growth. This generalization has an important bearing on the whole problem of physiological balance in nutrient solutions and furnishes what may be important suggestions bearing on our general conceptions of conditional control and conditional optima for plant activities.

THE RELATION OF THE CONCENTRATION OF THE NUTRIENT SOLUTION TO THE GROWTH OF YOUNG WHEAT PLANTS IN WATER-CULTURES

By S. F. TRELEASE

In these experiments the salt proportions were the same in all the different solutions of each series, but the solutions differed from each other in total concentration. Three series of cultures, all carried out at the same time, are considered, each series including a concentration range of from 0.5 to 7.0 atmospheres. A different set of salt proportions was used in each series. Six plants were grown in each culture and the cultures were in duplicate, upon a rotating table. The experiment lasted for 32 days, from January 23 to February 24, 1917, the solutions being renewed every 4 days.

In the first series the nutrient solutions contained the 4 salts KH_2PO_4 , MgSO_4 , KCl , and $\text{Ca}(\text{NO}_3)_2$ in the following relative molecular proportions: 1.000, 0.587, 0.485, 0.341. The average dry weight of tops and the average total water loss by transpiration, for six plants, are shown in the following table, which also shows the total concentration employed in all three series.

Concentration, <i>atm.</i>	Dry Weight, Tops, <i>grams.</i>	Transpiration, <i>cc.</i>
0.5	0.926	651
1.0	0.947	618
1.6	1.152	646
2.5	1.117	554
3.5	1.030	468
4.5	0.904	386
5.5	0.821	311
7.0	0.769	246

For this particular set of salt proportions the maximum yield of tops was obtained when the nutrient solution had a total osmotic concentration of 1.6 atm. With lower concentrations growth was considerably less, as is also true, and to a greater degree, with concentrations above the optimum. Between the concentrations 1.6 and 7.0 atm. the dry weight of tops is approximately a linear function of the concentration, the dry weight decreasing as the concentration increases. The transpiration values show the same general relation to the concentration, except that below 1.6 atm. the decrease is less clearly shown; in fact, with a concentration of 0.5 atm. the transpiration is slightly higher than with 1.6 atm.

In the second series the culture solutions were the same as those just described, except that KCl was not included. In these cultures the relations of dry weight and transpiration, to total concentration, were essentially the same as in the cultures of the first series, with KCl.

In the third series the salts used were the same as in the first, but in different relative molecular proportions, as follows: 1.000, 1.155, 7.282, 0.699. The relation between transpiration and concentration was the same as in the first series, but in this case there was a perfectly definite maximum of transpiration at 1.6 atm. For production of dry weight of tops, however, while the general relation to concentration was the same as in the first two series, the optimum concentration was 4.5 instead of 1.6 atm.

The interesting features of these results may be summarized as follows: (1) Transpiration and dry weight showed an approximately linear relation to the concentration of the medium above the optimum, these decreasing with an increase in concentration. (2) The optimum concentration for dry

weight of tops was altered from 1.6 atm. to 4.5 atm. by changing the proportions of the four salts used in the first and third series. (3) With the salt proportions of the three other salts used in the first series, the omission of KCl did not alter the relation between growth and concentration.

THE EFFECT OF RENEWAL OF CULTURE SOLUTIONS ON THE GROWTH OF YOUNG WHEAT PLANTS IN WATER-CULTURES

By S. F. TRELEASE and E. E. FREE

One of the practical problems in work with water-cultures is that of the frequency with which the culture solution must be renewed in order to obtain the best results. This note reports experiments in this connection on the growth of young wheat plants in the nutrient solution found by Shive¹ to be best for the production of dry weight of tops in wheat. The culture jars had a capacity of 250 cc. Six plants were grown in each jar and each culture was in triplicate. The volume of the culture solution was made up to normal by the addition of distilled water every 4 days or oftener. The details of the technique were the same as employed by Shive. All cultures ran 41 days, from January 6, to February 16, 1916. The results are given in the following table, in the form of dry weights of tops produced, each weight being the average of the three parallel cultures.

	Dry Weight. grams.
Changed daily	1.243
Changed every 3 days	1.012
Changed every week	1.020
Changed after 1 week, then every 3 days	0.995
Changed every 2 weeks	0.780
Changed after 2 weeks, then every 3 days	1.131
Changed after 2 weeks, then every week	0.969
Changed after 1 month	0.654
Not changed at all	0.621

¹ Shive, J. W., "A study of the physiological balance in nutrient media." *Physiol. Res.* 1: 327-397. 1915.

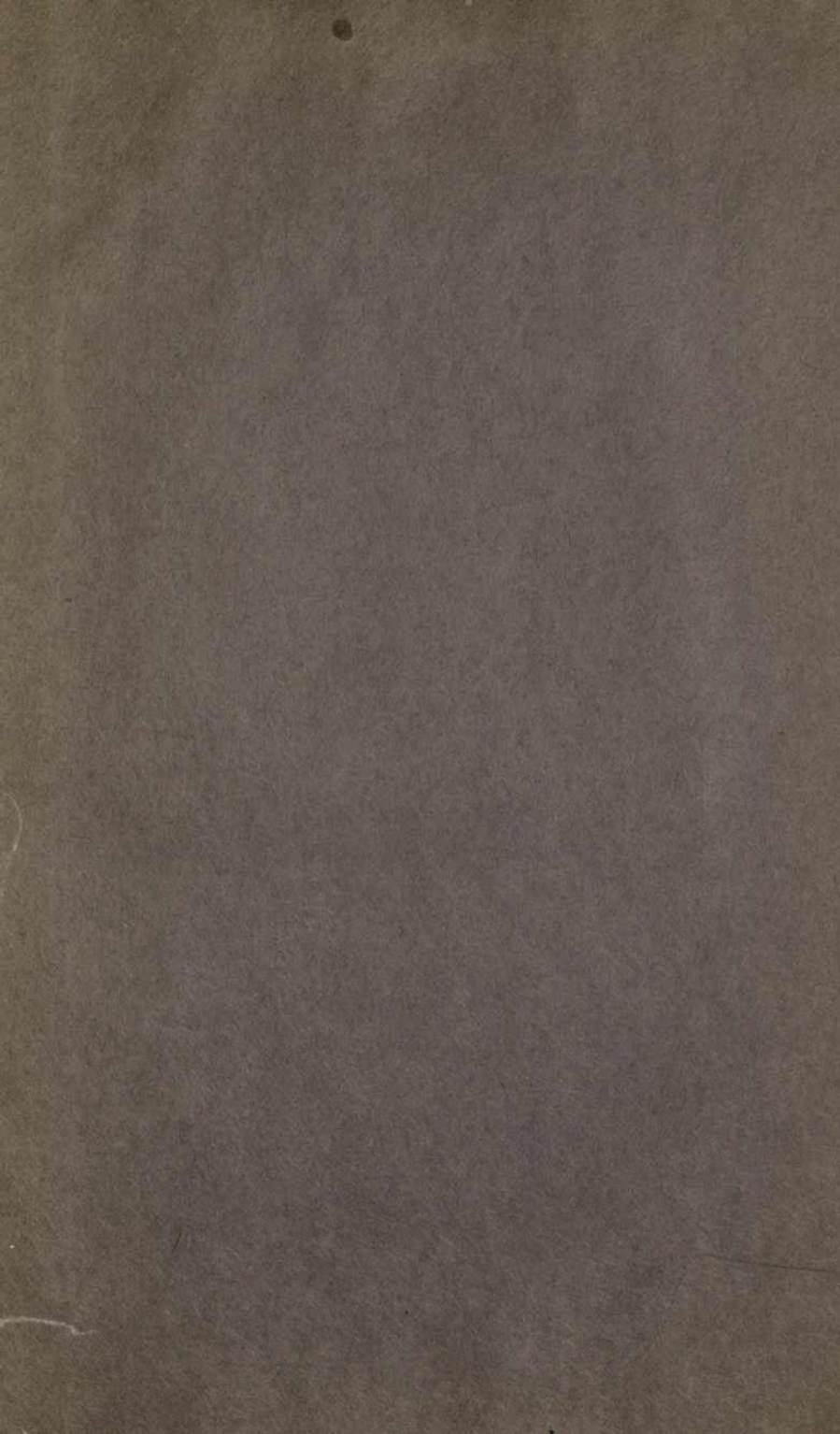
It is apparent that the yield is better the more frequently the solution is changed. If, after an initial period, the frequency of changing is increased the yield is improved. It is important, practically, that there is small difference between the cultures changed every 3 days and those changed every week. Daily change produces substantial improvement. Allowing the solution to remain unchanged for so long as 2 weeks is markedly injurious.

The above cultures were grown on a rotating table. An additional set was grown in the same greenhouse at the same time but not on the rotating table. The results follow:

	Dry Weight. grams.
Continuous flow of solution through culture jar at rate of about 1 liter daily	1.678
Changed every 3 days	1.222
Not changed at all	0.666

This experiment is not strictly comparable with the one done on the rotating table, but it seems probable that continuous flow of the solution must be regarded as more beneficial even than daily change.

Parallel with the experiments on the rotating table, one set of three cultures was treated by removing the solution weekly and shaking it with bone black. The solution was then filtered and restored to the culture jars. These cultures gave an average yield of 0.780 gram, as compared with 0.621 gram for the unchanged culture not treated with bone black. Evidently the bone black treatment improved the solution slightly but did not correct in important degree the harmful effects of infrequent changing. It was noticed incidentally that the magnesium injury that is characteristic of this solution, for wheat, appeared more frequently and severely when the changing was frequent than when it was not. The color of the plants was greener in the more frequently changed solutions.



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